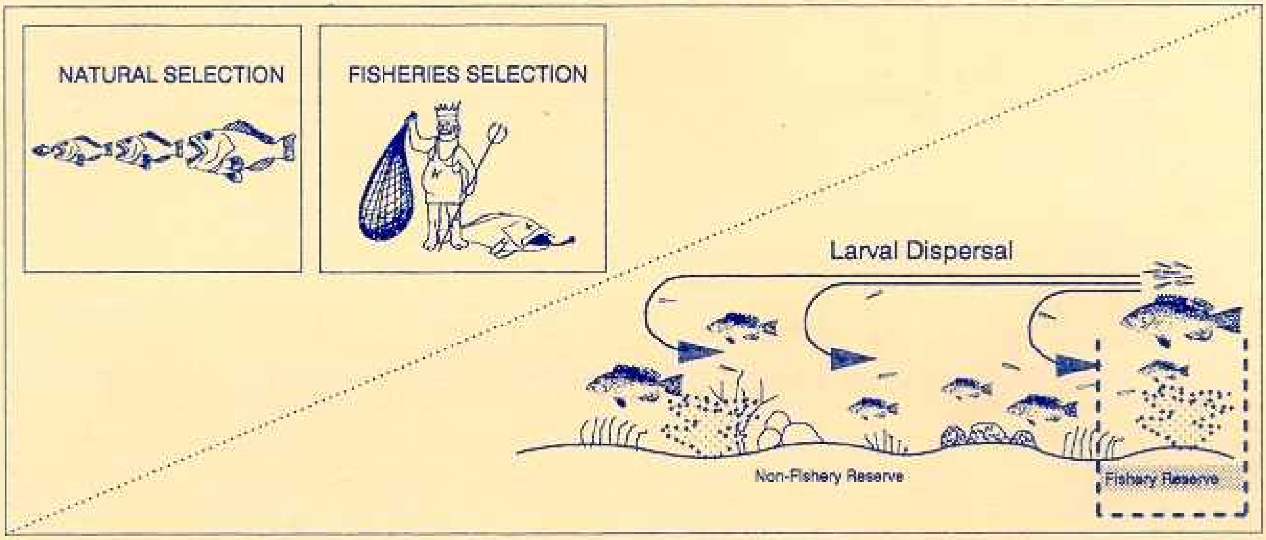
NOAA Technical Memorandum
NMFS-SEFC-261

The Potential of Marine Fishery Reserves for Reef Fish Management in the U.S. Southern Atlantic



April, 1990

Prepared by:

Plan Development Team[1]
Reef Fish Management Plan
South Atlantic Fishery Management Council

U. S. DEPARTMENT OF COMMERCE
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South Atlantic Fishery Management Council

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April, 1990

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NOTICE

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The Potential of Marine Fishery Reserves for Reef Fish Management in the U.S. Southern Atlantic

ABSTRACT

Marine fishery reserves (MFRs), areas with no consumptive usage, are recommended as a viable option for management of reef fisheries in the U.S. southern Atlantic region. MFRs are designed to protect reef fish stocks and habitat from all consumptive exploitation within specified geographical areas for the primary purpose of ensuring the persistence of reef fish stocks and fisheries. Fishery reserves are intended to protect older and larger fishes. This will benefit reef fisheries by protecting critical spawning stock biomass, intra-specific genetic diversity, population age structure, recruitment supply, and ecosystem balance while maintaining reef fish fisheries. The MFR concept is easily understandable by the general public and possibly more easily accepted than some other management strategies. Fishery reserves provide some insurance against management and recruitment failures, simplify enforcement, and have equitable impact among fishery users. Data collection needs solely for management are reduced and management occurs without complete information and understanding about every species and interaction. Use of fishery reserves will establish U.S. leadership in producing model strategies for cooperative international reef resource management in the Caribbean. Large resident fishes that wander out of reserves can help maintain certain trophy fisheries. MFR sites with natural species equilibrium will allow measurement of age, growth, and natural mortality for fisheries purposes and will provide a basis for other educational, economic, and scientific benefits. Because there is no fishing within MFRs, impacts of hook and release mortality are eliminated and the temptation for incidental poaching is reduced. A mixed management strategy is recommended where 20% of the shelf is MFR while the remaining 80% is managed for optimal yield by any of several traditional options. Coordinated fishery reserve efforts in state waters would enhance the benefits of MFRs.

Obstacles to fishery reserves include automatic resistance to new approaches in U.S. marine fisheries, opposition by some local special interests near proposed reserves, and uncertainty concerning the size, location, and number of reserves necessary to ensure persistence of the reef fish fisheries. The incentive for deliberate poaching may be increased within reserves; thus, at-sea surveillance and enforcement may be necessary. New artificial reefs may be needed to replace those lost by inclusion within fishery reserves. Other fishery management plans should be coordinated to control trolling and other fishing activities within reserves that may impact reef fishes. The short-term impacts on total harvest caused by placing fishing habitat into fishing reserves should be compensated for by long-term fishery benefits.

EXECUTIVE SUMMARY

Reefs comprise an important, highly productive, complex ecosystem in the southeastern United States that supports a high diversity of species and fisheries. The ecology and life history characteristics of reef fishes make them highly vulnerable to overfishing. Characteristics of particular concern are the sedentary post-settlement life history stages, low natural mortality, slow growth, long life, multiple reproductions, increased fecundity with size, and geographically restricted distribution associated with reef habitats. Larger individuals are frequently targeted and are more vulnerable to fishing gear.

Despite a lack of comprehensive long-term data for most reef species, indications of reef overfishing are found worldwide, but are of particular concern here in the U.S. southern Atlantic region. Collecting adequate data for statistical treatment of individual species appears impractical because of the number of reef species and the different components of the fishery in terms of numbers of users, gear types, and access ports.

Major problems identified in the reef fish fishery include:

1. Potential recruitment overfishing because of insufficient spawning stock biomass;
2. Increased probability of recruitment failure due to environmental uncertainty and shorter generation times;
3. Loss of genetic diversity within species resulting in undesirable stock characteristics;
4. Growth overfishing for many species;
5. Declines in overall abundance and average fish size;
6. Loss of biotic (interspecific genetic) diversity;
7. Potential disruptive reef fish community instability and permanent alterations; and
8. Faster selection against desirable traits due to shorter generation times.

All these problems are of the utmost concern for fishery management. Recruitment overfishing results from an insufficient number of recruits produced because of (1) fewer fish surviving to become spawning adults, (2) the shortened average individual life expectancy of adults, and (3) reduced average spawning size caused by differential removal of larger individuals by fishing. Ecological instability or deleterious permanent community change are also potential problems due to the selective removal of predators.

Evolutionary theory predicts that sustained fishing mortality will result in loss of genetic diversity that will be deleterious to the fishery. Even though a species may persist, it will tend to be smaller and less valuable to the fishery because more food resources will be diverted into egg production and less into growth. Surviving individuals are likely to remain small and reproduce at younger ages.

Fishery effects on stocks were modeled using red snapper as a representative, widely distributed, important reef fish species. Fishing mortality had major effects on age structure, population size, and spawning stock biomass. High fishing mortality resulted in fewer adults, less total egg output, and reduced average spawning age. These changes have three important implications for the reef fish fishery. First, recruitment failure is more likely because of greatly reduced egg production. Second, a shorter average life span increases the chance of population collapse after several poor recruitment years triggered by natural ecological cycles. This collapse could occur even if fishing mortality was at an acceptable level for average conditions. Third, shorter generation time speeds up evolutionary responses due to genetic changes caused by fishing mortality. We concluded that some older fish are more valuable as egg producers and for protecting the quality of genetic composition than for the value of their flesh. Fishery management should provide some protection for population age structure, species composition, and genetic variability.

The concept of marine fishery reserves (MFRs), areas with no consumptive fishing, were investigated because past fishery management actions (i.e. size limits) appear to have had limited effect on reducing fishing mortality and did not treat certain fishery problems. MFRs, are ideally suited for reef fishes because of their sedentary and highly philopatric adult stages. Other administrative options for reef fish management were considered but appeared ineffective or not feasible. These included minimum and maximum size limits, gear restrictions, limited entry, closed seasons, pulse fishing, bag limits, quotas, artificial reefs and stocking programs.

The Plan Developement Team (PDT) recommends a mixed management strategy where 20% of the habitat is held in fishery reserves while the other 80% is managed by traditional methods to optimize yield. MFRs would be scattered throughout the U.S. southern Atlantic region in order to protect approximately 20% of the reef fish spawning stock biomass.

The optimum number, location, and sizes of fishery reserves needed are unknown, but estimates were made and sites suggested based on available biological and sociological information. Representative sites were suggested throughout the southeastern region beginning at state waters and ending at 150 fathoms. More precise location was not possible because of the lack of scientific knowledge concerning specific habitat requirements for most species. A variety of reef habitat types exist with different quantity, quality, and dispersion throughout the region and with different importance to various species. Also, many reef species extensively use non-reef habitat for recruitment, growth, or foraging.

A minimum coastal boundary of 20 mi (32 km) was recommended in order to facilitate enforcement and to include probable home ranges of core populations. Where possible, nominated sites were accessible to enforcement personnel and away from major population centers. Similar fishery reserves in state waters could enhance MFR benefits.

Anticipated problems in establishing MFRs were evaluated. Obstacles to fishery reserves include resistance to new management approaches in U.S. marine fisheries, opposition by some local special interests near proposed reserves, and uncertainty concerning the size, location, and number of reserves necessary to ensure persistence of the reef fish fisheries. The incentive for deliberate poaching may be increased within MFRs and at-sea surveillance and enforcement may be necessary. New artificial reefs may be needed to replace those lost by inclusion within fishery reserves. Other fishery management plans should be coordinated to control trolling and other fishing activities within reserves that may impact reef fishes. The inclusion of fishing habitat into fishing reserves will have short-term impacts on total harvest that should be compensated for by long-term fishery benefits.

Marine fishery reserves offer the most potential for benefiting marine reef fisheries by protecting critical spawning stock biomass, intraspecific genetic diversity, population age structure, recruitment supply, and ecosystem balance while maintaining reef fish fisheries. MFRs offer several secondary beneficial features. The use of fishing reserves is an easily understandable concept for the general public and may be more readily accepted than other management strategies: terrestrial wildlife reserves are common and widely accepted. MFRs provide insurance against management and recruitment failures, have an equitable impact among fishery users, and enforcement needs are simplified. Data collection needs are reduced and management can occur without complete information and understanding about every species and ecosystem interaction. Use of fishery reserves will establish U.S. leadership in producing model strategies for cooperative international reef resource management in the Caribbean. Large resident fishes that wander out of reserves can help maintain trophy fisheries that would not exist under other management approaches. MFRs at equilibrium will allow measurement of age, growth, and natural mortality for fisheries purposes and will provide a basis for other educational, economic, and scientific benefits. Problems concerning impacts of hook and release mortality are eliminated within MFRs and the temptation for incidental poaching is reduced.

"In wildness is the preservation of the world."
Henry David Thoreau, 1862

INTRODUCTION

Marine fishery reserves (MFRs) are a potential reef resource management tool for the South Atlantic Fishery Management Council (SAFMC). MFRs are designed to protect reef fish stocks and habitat from all consumptive exploitation within specified geographical areas for the primary purpose of ensuring the persistence of reef fish stocks and fisheries. In this paper we review problems of the reef fish fishery and evaluate the potential advantages and disadvantages of MFRs relative to alternative management options. Red snapper are modeled as a representative reef fish species because they are a major fishery species with the most available biological information. The SAFMC Reef Fish Plan Development Team (PDT) recommends a mixed management strategy where 20% of the habitat is held in fishery reserves while the other 80% is managed by traditional methods to optimize yield.

BACKGROUND

Reef Fish Ecology

Reef fish are widely distributed in the U.S. southern Atlantic region (Chester, et al., 1984) and comprise many species associated with hard substrate. Major reef habitats include coral reefs, rock outcrops, and artificial reefs. Parker et al. (1983) conservatively estimated that reef habitat accounted for approximately 14% of the shelf between Cape Hatteras and Cape Fear, N.C. and 30% of the bottom between Cape Fear and Cape Canaveral, Florida. Unfortunately, detailed knowledge about the quantity, quality, distribution and types of reef habitat and their relative importance to various species is limited and is likely to remain so for the foreseeable future. Although reefs cover only a small portion of the ocean bottom, they are one of the world's most highly productive ecosystems (Odum, 1971). Reef productivity in the Caribbean, for example, is 8 to 220 times greater than oceanic waters (Munro, 1983). The estimated standing crop of fishes on and around coral reefs may be 20 to 30 times greater than in temperate waters (Munro and Williams, 1985).

Reef fish life history for most exploited species is characterized by slow growth, low adult natural mortality, long life, large body size, and multiple reproductions (iteroparity) (Manooch, 1987). Larger body size is an advantage to many reef fishes under natural conditions, allowing individuals to acquire more food, secure mates, defend territories, and escape predation (Menge and Sutherland, 1976, 1987). Fecundity (in terms of the number of eggs produced) increases with age, is usually exponentially related to fish size, and is correlated more with weight than length (Nikolskii, 1980). Senescence often occurs in older individuals of long-lived species. In many exploited species, particularly grouper, older individuals change sex from female to male.

The dispersal and replenishment of reef fish populations has been reviewed by Ehrlich (1975), Sale (1980), Richards and Lindeman (1987), and Doherty and Williams (1988). Reef fishes undergo a bipartite life cycle consisting of pelagic larvae and demersal adults. Most dispersal occurs during the pelagic phase (larvae or eggs) which may last from a week to two months before settlement. After settlement most juveniles and adults tend to be rather sedentary, remaining on a particular reef or within a limited geographical area for long periods (Bardach, 1958). Over the past decade the consensus among reef fish ecologists has changed radically: adult reef fish populations are no longer thought to be limited by habitat availability, but rather by the number of postlarval survivors (recruitment limited). Among unfished populations, recruitment variability (settlement and survival of juveniles) appears to be more important for adult population abundance than habitat availability (Doherty and Williams, 1988).

Reef Fisheries

Reef fisheries are extremely complex because of (1) the number of species involved, (2) the high degree of biological interactions between species, (3) the different objectives among fishing interests, (4) the different kinds of fishing gear used, (5) the number of access points, and (6) the extremely dynamic and opportunistic nature of the fishery. Exploited reef resources include: lobster, crabs, corals, mollusks, and many demersal and semipelagic fishes. Among finfishes, the U.S. South Atlantic Fishery Management Council Snapper Grouper Management Plan recognizes 69 species with commercial or recreational importance. Fishery objectives vary: commercial fishing usually seeks to maximize income with minimum cost and time expended; recreational fishing may seek to maximize fish size or simply avoid zero catches. Fishing gear includes traps, hook and line, bottom long lines, trawls, nets and spears. Each fishing gear typically harvests many species and may be employed from shore, small boat, or large vessel.

Fishery Trends

The vulnerability of reef fish to overfishing has been widely recognized to be due to their slow growth, long life, and limited adult mobility (Adams, 1980; Ralston, 1987). During the last decade, fishing pressure has increased in the U.S. southern Atlantic region because of increased use of more efficient fishing gear, greater use of sophisticated electronic equipment, and more fishing vessels resulting from larger coastal populations and increased public demand for seafood (Waters, 1988).

Fishing mortality can reduce stock abundance, size/age distributions, and may lead to changes in reef fish community structure (Munro and Williams, 1985). Newly exploited stocks are initially affected by removal of larger and older individuals (Fig. 1). This happens because larger fish have greater sport and economic value, are targeted by size-selective fishing gear, and are often more catchable because of their aggressive behavior (Thompson and Munro, 1974; Nelson and Soulé, 1987). When populations are near their environmental carrying capacity, fishing may increase total fish biomass production by allowing younger, faster-growing fishes to replace older, slower-growing fishes.

When fishing effort increases beyond optimum levels, overfishing may occur. Classic signs of overfishing include reduced total landings, declining catch per unit effort, shifts in catch to smaller sized individuals and different species, and recruitment failures (Pauly, 1979; Huntsman, et al., 1982; Munro, 1980; Polovina and Ralston, 1987). Growth overfishing occurs when fishes are caught before they have had adequate chance to grow. Much more severe is recruitment overfishing, when fishing reduces adult stocks, causing lower egg production and increased chance of recruitment failure. The spawning potential ratio (SPR)[1] can be used as a predictor of reproductive potential and recruitment overfishing (Goodyear, 1988a, 1988b; 1989). Empirical and theoretical studies suggest that stock collapse is highly probable when equilibrium spawning stock biomass (the weight of spawning fishes) goes below a critical minimum level of 20% of the unharvested level (Goodyear, 1988, 1989).

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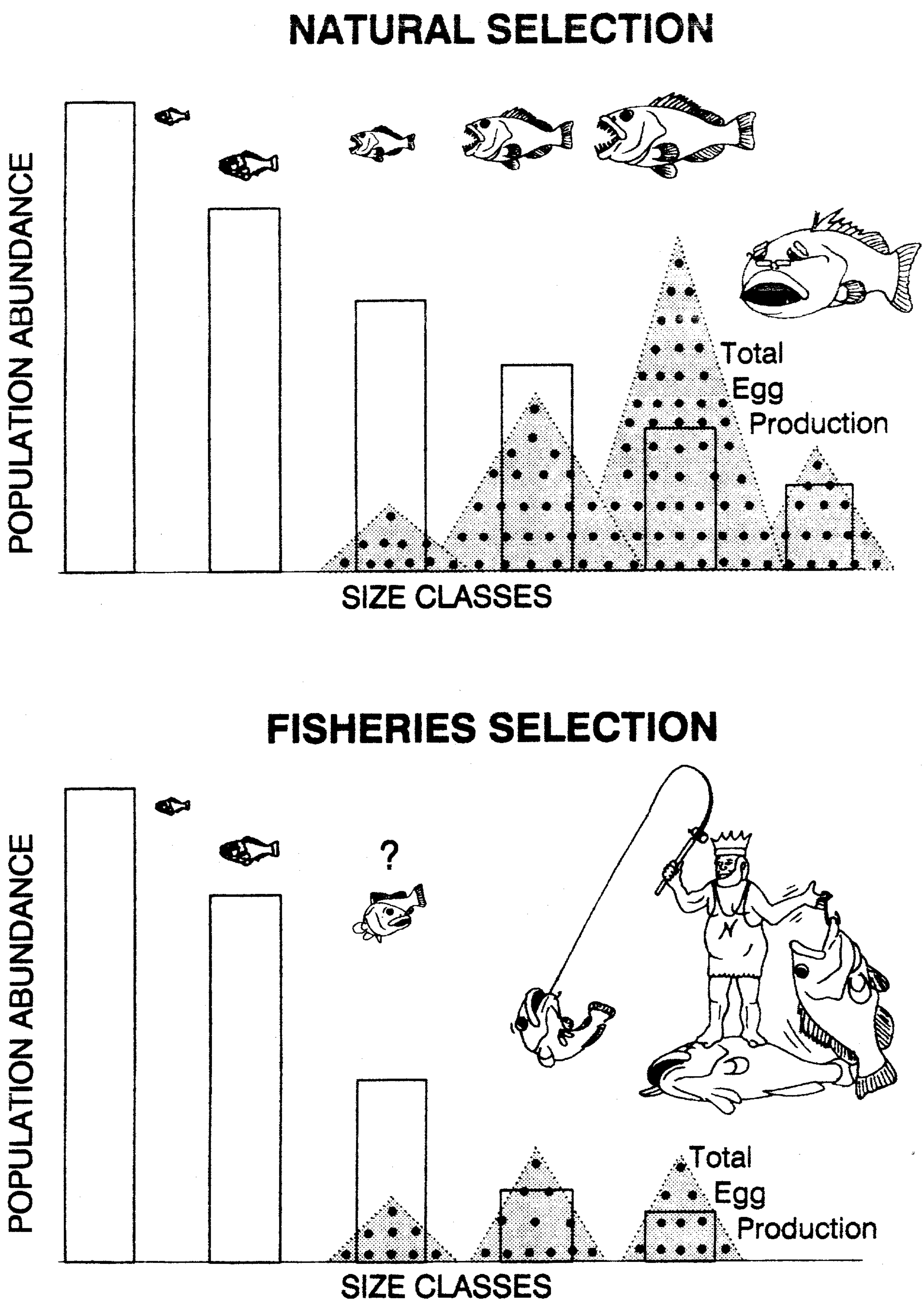
[1]The spawning potential ratio (SPR) is calculated as:

$$SPR = \frac{P_{fished}}{P_{unfished}} = \frac{SSBR_{fished}}{SSBR_{unfished}}$$

where P_{fished} is the potential fecundity of a recruit in the exploited stock; $P_{unfished}$ is the potential fecundity of a recruit in the absence of fishing mortality; $SSBR_{fished}$ is the spawning biomass per recruit which is the expected lifetime reproductive potential of an average recruit in a fished stock; and $SSBR_{unfished}$ is the spawning biomass per recruit which is the expected lifetime reproductive potential of an average recruit in an unfished stock (Goodyear, 1989).

Figure 1. Effects of intense fishing on population size structure and total egg production.



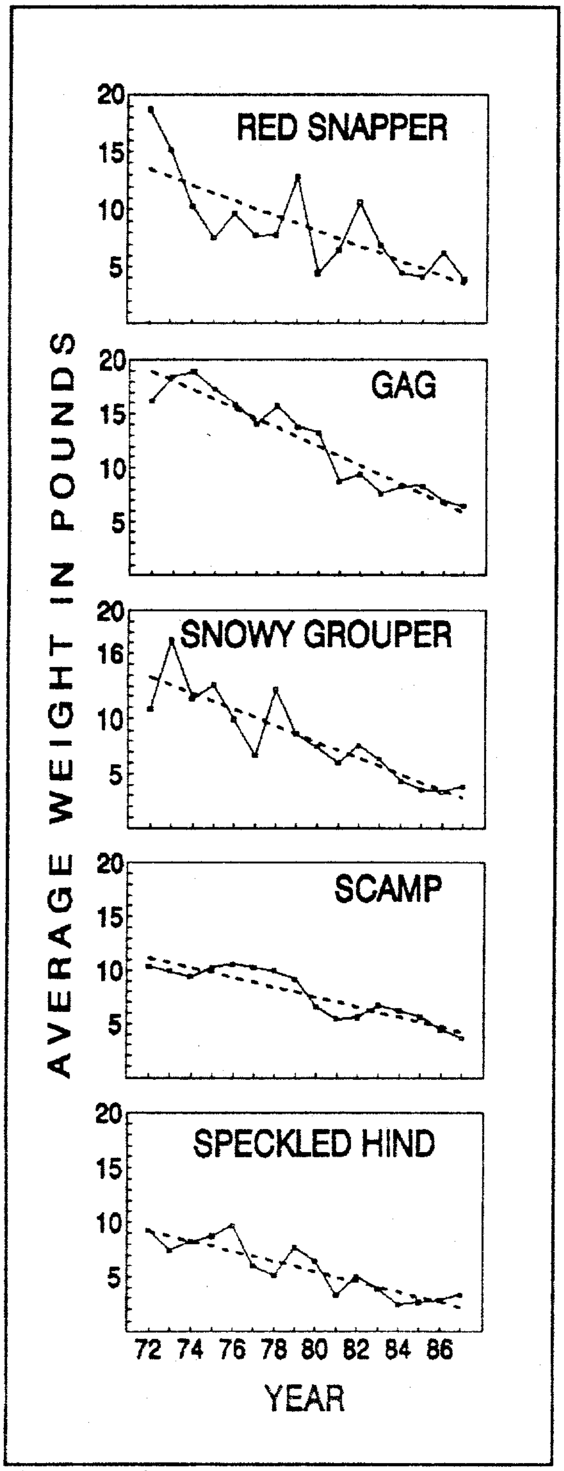


Figure 2 Changes in average size of the five initially largest important species caught in the U.S. southern Atlantic headboat fishery (Modified from Huntsman and Willis, in press).

Other kinds of overfishing refer to reef fish community structure. Ecosystem overfishing refers to community instability characterized by shifts or flips in dominance and relative abundance caused by reduced populations of certain key species, usually predators. Serial overfishing is a sequential loss of species over time. It usually starts with apex predators and occurs because fishing effort continues in a multispecies fishery even though a particular species may have become scarce (Munro and Williams, 1985). Species most likely to disappear are the ones with characteristics most valuable to the fishery such as large size and high catchability (Thorpe, et al., 1981). Within a population the more rapidly growing individuals may be caught at younger ages and thus are selected against (Bergh and Getz, 1989). Absence of larger individuals and species, correlated with fishing intensity, has been noted in the Caribbean (Munro, 1980, 1983; Appeldoorn and Lindeman, 1985; Bohnsack, et al., 1986; Koslow, et al., 1988; Bohnsack, 1989a), Gulf of Mexico (Goodyear, 1988a, 1988b), Atlantic (Bohnsack, 1982; Bannerot, et al.; 1987; Huntsman and Willis, in press), and Pacific Oceans (Craik, 1981; Russ, 1985; Munro and Williams, 1985).

Reef Fish Stock Assessment

The complexity of reef fisheries makes comprehensive data collection difficult, expensive, and often impractical. It is unlikely that sufficient data will be available in the foreseeable future to do comprehensive stock assessments of all species in the reef fish management unit. Reef fish stock boundaries are unknown and statistical data for many species have been aggregated into genus or family groups that make classical assessment of stock condition by species difficult or impossible. Legal limitations and funding availability often limit data collection efforts. In the U.S. southern Atlantic region, long-term data are not available for any reef fish species (Huntsman and Waters, 1987). The most complete data set began in the 1970's from the headboat fishery off North and South Carolina and from the NMFS-South Carolina MARMAP program. The MARMAP parogram has provided fishery-dependent and fishery-independent data showing fisheries trends (Low, et al., 1985, 1987; Collins, et al., 1987; Collins and Sedberry, in review) and had done research on offshore community structure; reef fish biology including life history, age, growth, and feeding habits that provide a basis for comparison with future assessments and studies (Low, 1981; Manooch and Barans, 1982; Waltz, et al., 1982; Wenner, 1983; Sedberry and Van Dolah, 1984; Sedberry, 1985, 1987, 1988, in press; Keener, et al., 1988).

Despite a lack of quantitative and historical data, declines of many reef fisheries have been recognized worldwide that demand immediate attention (Appledoorn and Lindeman, 1985; Munro and Williams, 1985; Russ, 1985; Goodyear, 1988a, 1988b). These trends include declining landings for various segments of the fishery, greatly increased fishing effort, reduced average and maximum sizes, and changes in species composition. Similar population declines are being noted in the U.S. southern Atlantic region for many reef fishes (Low, et al., 1985; Huntsman and Willis, in press; Collins and Sedberry, in review; Hommel, m.s.; Vaughan, et al., m.s.) and tilefish, a philopatric species in the reef fish management unit (Hightower and Grossman, 1988; Barans and Stender, m.s.). Eight of ten major species in the headboat fishery show declining trends in average size (Huntsman and Willis, in press) (Fig. 2 and 3). These declines are especially great for the five originally largest species (Fig. 2). Some species have become so rare in certain areas that statistical assessment is nearly impossible and special protection may be warranted, such as warsau grouper (Epinephelus nigritus) (Huntsman and Willis, in press; Burton, 1989), Nassau grouper (E. striatus) (Bohnsack, unpublished data), and jewfish (E. itajara) (Gulf of Mexico Fishery Management Council, 1989).

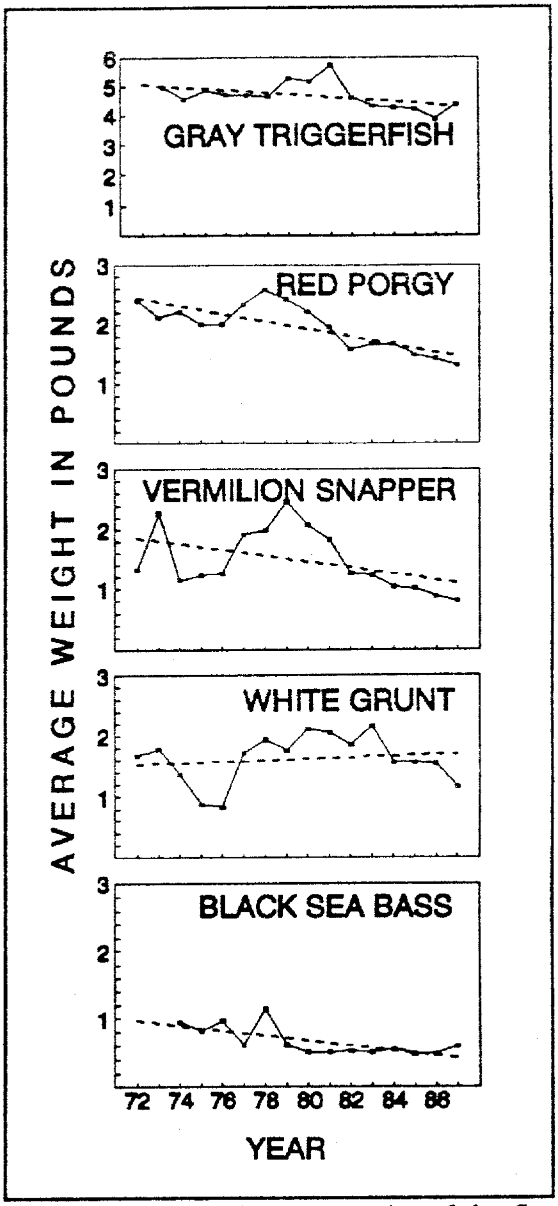


Figure 3 Changes in average size of the five smallest important species caught in the U.S. southern Atlantic headboat fishery (Modified from Huntsman and Willis, in press).

Evolutionary Theory

Fishing, unlike any other major source of human food production, depends on harvesting wild populations. An important fisheries concern is the potential selective effect of fishing mortality on stocks. From an anthropogenic perspective, fishing tends to remove individuals with desirable characteristics (e.g. large body size) which reduces their genetic output. In contrast, animal husbandry and other major sources of food production tend to protect desirable individuals and breed their characteristics into subsequent generations. Selective fishing may result in unfavorable population characteristics from a human perspective; instead of growing, fishes should respond to adult mortality by staying small and producing more eggs at younger ages.

Evolution by natural selection is the fundamental unifying concept in biology (Smith, 1989). Natural selection operates on biological variability: the fact that no two individuals are alike. Individuals who survive to reproduce will pass their genetically derived characteristics on to subsequent generations. Natural selection selects for characteristics that increase survival and the production of successful offspring. It tends to select against characteristics that reduce pre-reproductive survival.

Evolutionary theory predicts specific life history features (age, size, and reproductive effort) will occur in response to particular selective environmental factors (e.g. Murphy, 1968; Rago and Goodyear, 1987). Many life history features result from a tradeoff between growth and reproductive effort (Partridge and Harvey, 1988). For example, juvenile reef fishes use a significant proportion of food resources for growth and essentially nothing for reproduction. Adults, however, divert most of their food resources from growth to reproduction (Fig. 4).

Reef fish life history characteristics of low natural mortality rates, long life, slow growth, and iteroparity are predicted under conditions of high uncertainty for pre-reproductive survival (recruitment variability) and limited adult mortality (Murphy, 1968; Partridge and Harvey, 1988). Organisms must live a long time to ensure successful reproduction; larger individuals produce more gametes and have greater chances of successful reproduction. However, high externally-imposed adult mortality, such as from fishing, selects for increased reproductive effort at young ages, resulting in early maturity, shorter life spans, smaller sizes, and semelparity (single reproductive episodes) (Table 1).

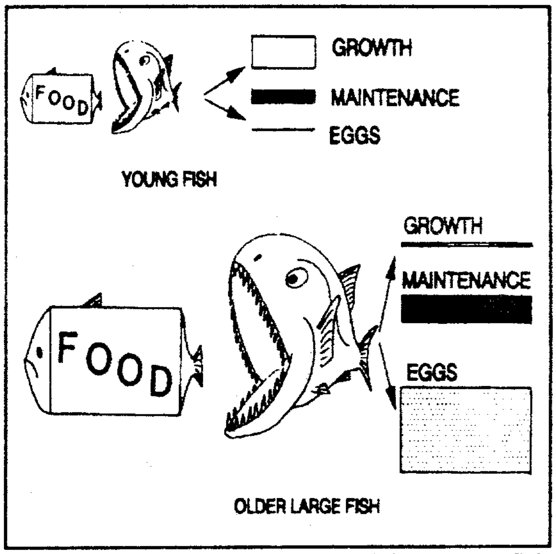


Figure 4 Food conversion model. Young fish divert more food resources into growth than reproduction. Adults divert more food resources into reproduction than growth.

Support for predictions of evolutionary theory have been provided by recent empirical research showing that many unexploited reef fish populations appear to be recruitment limited in that adult population size depends on the number of surviving postsettlement juveniles (Doherty and Williams, 1988). Reznick and Endler (1982) experimentally confirmed predicted effects of adult mortality on life history responses with fish, using Poecilia reticulata as prey and Crenicichla alta as a predator that prefers to feed on mature prey. Reproductive effort was increased in areas dominated by Crenicichla alta, versus areas with predators that preferred smaller fish or that showed no size preference. Higher adult mortality selected for an increased percentage of body weight devoted to developing offspring, shorter interbrood intervals, and maturity at smaller sizes. Shifts in sexual maturity to smaller sizes and younger ages have been noted for vermilion snapper, Rhomboplites aurorubens, (Collins and Pinckney, 1988) and for gag grouper, Mycteroperca microlepis, (Collins, et al., 1987).

Table 1. Reef Fish Selective Forces and Life History Features.

	NATURAL CONDITIONS	HIGH FISHING PRESSURE
SELECTIVE PRESSURE:	Low Adult Mortality	High Adult Mortality
	High Recruitment Uncertainty	Same
LIFE HISTORY TRAITS SELECTED:	Long Life	Shorter Life
	Multiple Reproductions	Fewer Reproductions
	Large Adult Size	Smaller Adult Size
	Delayed First Reproduction	Early Reproduction
	Slow Growth to Maximum Size	Rapid Growth

Population Genetics

"In surveying the causes of loss of genetic diversity we are struck by how often the conspirators are not the expected Ignorance and Greed but, rather, the equally dangerous Partial Knowledge and Good Intentions."

Nelson and Soulé (1987)

An awareness has developed in recent years that genetics is the central concern in biological conservation and that a consideration of genetic effects on exploited fishes is essential to successful fisheries management (Allendorf, et al., 1987; Ryman and Utter, 1987; Kapuscinski and Philipp, 1988). Nelson and Soulé (1987) consider preservation of gene pools the primary obligation of fisheries management. Although genetic problems associated with fishery activities have been recognized, they have usually been ignored by managers, often with detrimental consequences (Allendorf, et al., 1987; Nelson and Soulé 1987; Courtenay and Robins, 1989).

Population genetics and selection are discussed in detail by Levins (1968), Wilson and Bossert (1971), Lewontin (1974), Charlesworth (1980), Smith (1989) and others. A genome is the entire genetic complement of the individual. Genotype refers to all the genetic characteristics that determine an organism's structure and function. Phenotype is the outward appearance of an organism based on the physical expression of the interaction between the genotype and environment.

Natural selection operates directly on an individual's phenotype. The direction and speed of selection depends in part on the population generation time, stock size and structure, genetic heritability, genetic variability, and the intensity of selection (Smith, 1989). Selection of a quantitative character depends in part on heritability, the proportion of the total variance of a character which is of additive genetic origin. To predict the rate of response to selection the selection differential must be determined. This is the deviation from the mean of the unselected population of the mean phenotypic value of the parents. The actual selection response is the deviation of the mean value of their offspring from the mean of the unselected population.

Fisheries present unique genetic problems because they harvest wild populations. Overwhelming evidence exists for species and stock succession by fisheries activity; however, detecting fisheries selection within stocks is extremely difficult (Nelson and Soulé, 1987). Fishes exhibit extremely high phenotypic variability compared to other vertebrates and determining the genetic basis of this variability is extremely difficult, partly because of a considerable environmental component related to fish poikilothermy and indeterminate growth capacity (Allendorf, et al., 1987). The combination of phenotypic variability coupled with an apparent intraspecific structuring of many fish species have confused the genetic-phenetic relationships that have delayed application of genetics and theory to fisheries management.

Koehn and Hilbish (1987) noted that determining the precise genetic basis for specific features that vary among individuals of a population (i.e. polymorphic) is usually impossible. The age and size-structure of reef fishes also complicates analysis of fishing selection effects (Charlesworth, 1980). Lewontin (1984) showed that the underlying conditions of heterogeneity determine whether the use of gene frequencies or morphological differentiation may better detect differences between populations. Also, changing patterns of a population as a whole may mask actual changes for subpopulations or individuals for statistical reasons (Vaupel and Yashin, 1985).

Fishing mortality changes the quantity and quality of egg production. It reduces the total number of fertilized eggs and the genetic input of large adults into the next generation. Among protogynous hermaphrodites (i.e. they change sex from females to males) such as grouper, heavy fishing mortality can change the sex ratio so that the number of males can become limiting, especially if mating is random (Bannerot, et al., 1987). This reproductive strategy insures that at least half of the genetic input for each egg has come from a parent that has been environmentally tested (i.e. it successfully survived long enough to reproduce as a male). When heavily fished, transformation to males occurs at younger ages and sizes, which affects the quantity of reproductive output and perhaps the quality.

The amount of reproductive output is frequently maintained by stabilizing selection, which involves the disproportionate elimination of extremes. Animals tend to maximize fitness (the genetic contribution by an individual's descendants to future generations) by producing the number of eggs which result in the maximum number of young surviving to reproduce (Emlen, 1973). Too few eggs results in reduced parental fitness. Too many eggs results in reduced probability of survival due to reduced average parental input of materials into each egg.

Directional selection is the favoring of one genetic extreme and is responsible for progressive evolutionary change in populations. The genetic process of directional selection has been documented in natural populations of many species, in laboratory experiments, and in breeding programs with economically significant plant and animal species (Beardmore and Shami, 1979). Artificial directional selection imposed on a system maintained by stabilizing selection can result in the loss of intraspecific (within a species) genetic diversity. Beardmore and Shami (1979) found that under stabilizing selection for caudal fin ray number in Poecilia reticulata, older cohorts were significantly more heterozygous than younger cohorts, and that progeny from larger broods were significantly more heterozygous on average than progeny from smaller broods. Extreme phenotypes which were more heterozygous survived better than those which were more homozygous. Also, more extreme phenotypes were more homozygous than central or optimal phenotypes.

Fishing mortality represents classical directional selection against large size and reproduction among older individuals. The long term impacts of selective fishing should concern resource managers; although a species could continue to persist under heavy fishing pressure, its characteristics could be quite different due to intraspecific genetic loss. Bergh and Getz (1989) show that fishing can lead to a loss of genetic diversity in a panmictic population or to the loss of a competing species. They concluded that "When catchability increases sufficiently with body size, then harvesting preferentially removes the most productive genotypes, and this causes a

Figure 5. Intense adult mortality favors selection for smaller adult size and earlier reproduction.

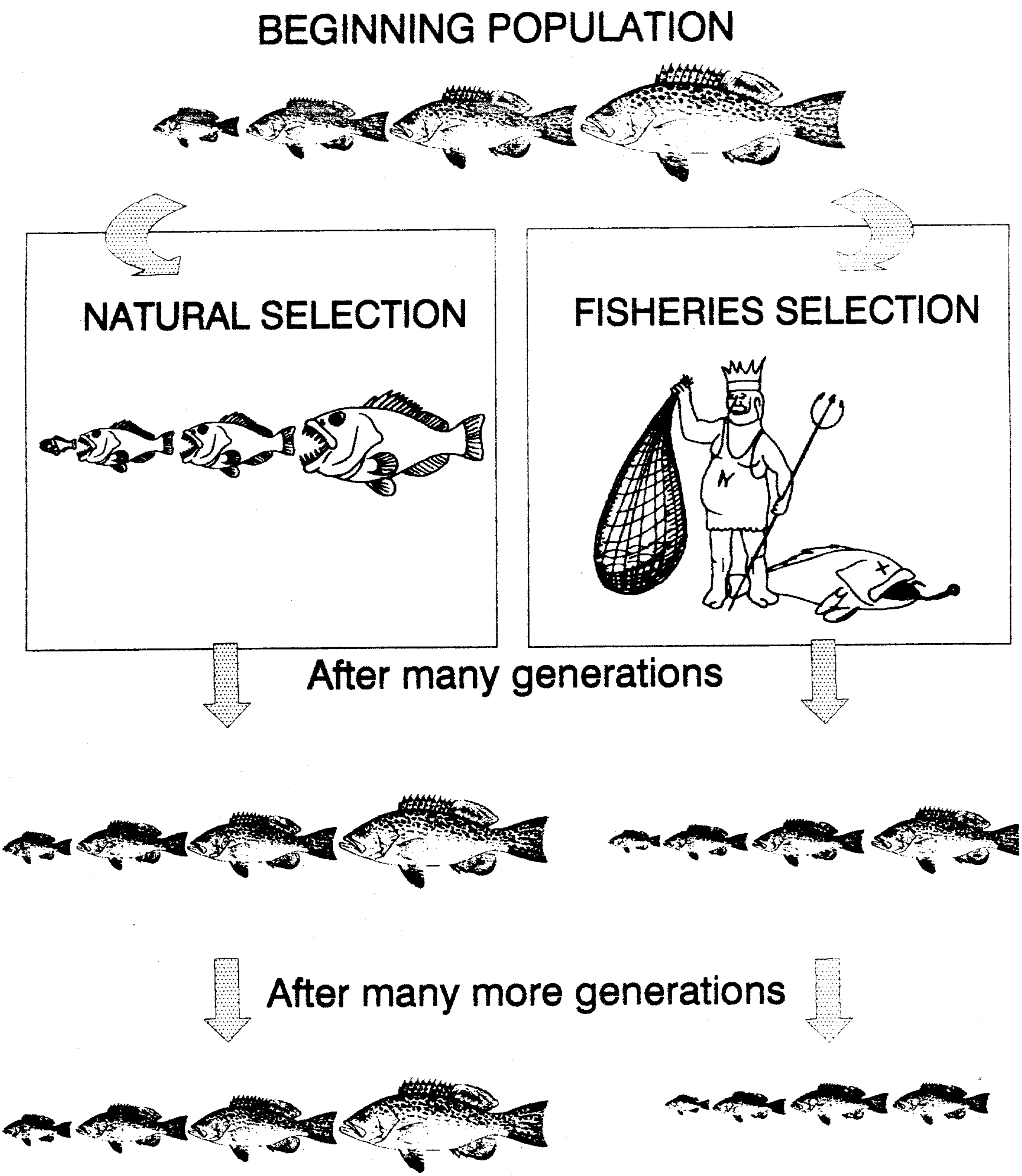


Table 2. Reported ratios of fishing mortality to natural mortality estimates (F/M) for selected reef fish families. Modified from Ralston (1987, Table 8.2).

Species	F/M	Source
Snapper (Lutjanidae)		
Lutjanus campechanus	1.25	Nelson and Manooch (1982)
	1.63	Nelson and Manooch (1982)
	1.26	Nelson and Manooch (1982)
	3.30	Nelson and Manooch (1982)
Lutjanus purpureus	1.66	Ivo and Gesteira (1974)
	1.94	Ivo and Hanson (1982)
	2.23	Ivo and Hanson (1982)
	1.73	Ivo and Hanson (1982)
Pristipomoides filamentosus	1.92	Ralston (1974)
Pristipomoides flavipinnis	1.33	Ralston and Williams (unpub., cited in Ralston, 1987)
Grouper (Serranidae)		
Centropristis striata	1.77	Low (1981)
	1.00	Low (1981)
Epinephelus drummondhayi	0.85	Matheson and Huntsman (1984)
	0.35	Matheson and Huntsman (1984)
Epinephelus guttatus	0.28	Thompson and Munro (1974)
	0.28	Thompson and Munro (1974)
	1.35	Sadovy and Figuerola (in press)
	1.06	Sadovy and Figuerola (in press)
Epinephelus niveatus	0.27	Matheson (1982)
	1.80	Matheson (1982)
	1.93	Matheson and Huntsman (1984)
	0.67	Matheson and Huntsman (1984)
Epinephelus sexfasciatus	0.71	Pauly and Ingles (1982)
Epinephelus striatus	2.52	Olson and LaPlace (1979)
Mycteroperca microlepis	3.00	McErlean (1963) Ralston (1987)
Mycteroperca phenax	1.24	Matheson et al. (1984)
Tilefishes (Malacanthidae)		
Lopholatilus chamaeleonticeps	3.00	Hightower and Grossman (1988)
	5.60	Hightower and Grossman (1988)

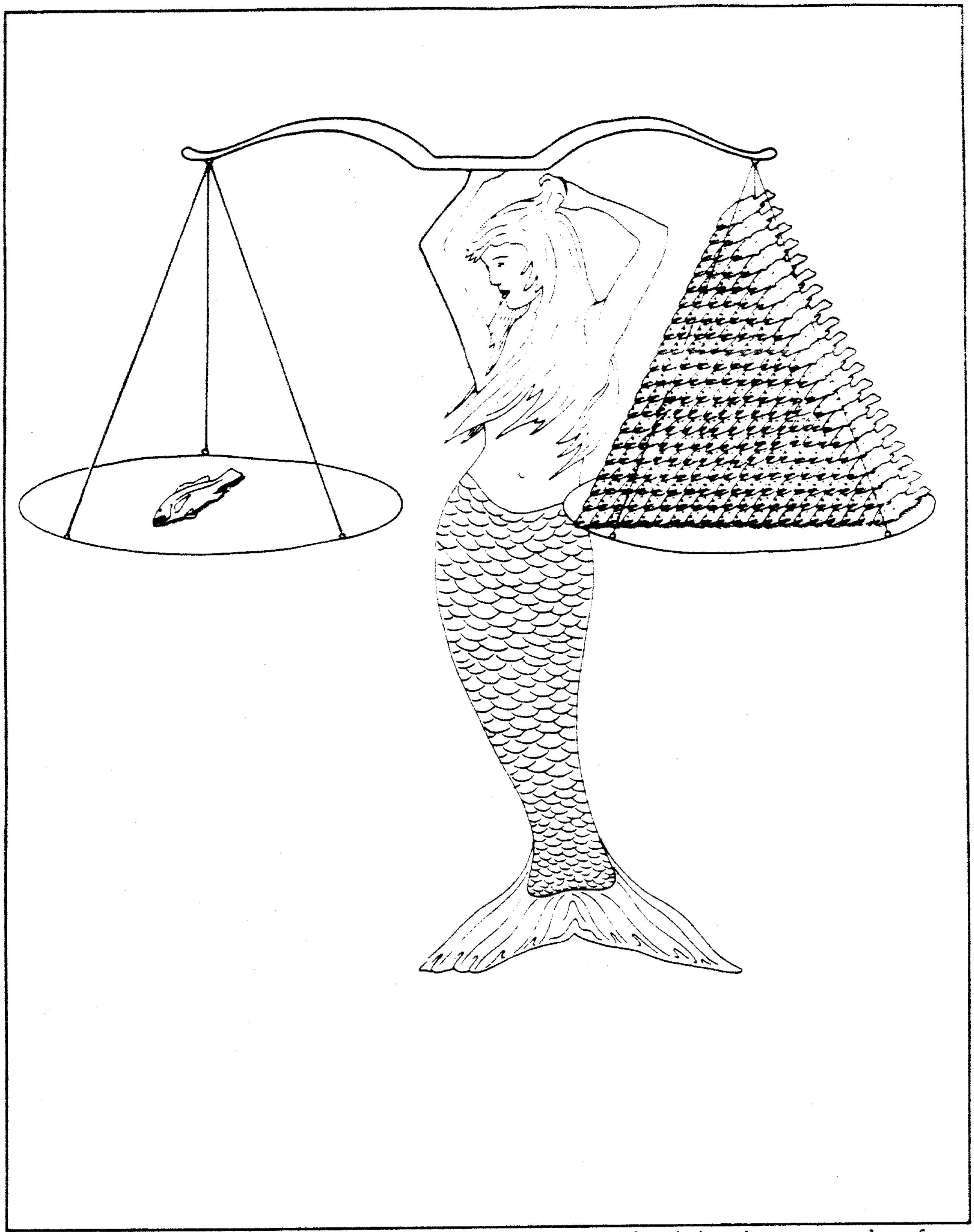


Figure 6 Equivalent red snapper fecundity. One 61 cm (12.5 kg) female has the same number of eggs (9,300,000) as 212 females at 42 cm (1.1 kg each).

reduction in the maximum sustainable yield of the population. Harvesting can also reverse the relative fitness of genotypes, since a rare inferior genotype in an unexploited population may be more fit under fishing." One likely result is selection for smaller adult sizes (Table 1; Fig. 5). The fact that fishing mortality rates often exceed natural mortality rates (Table 2; Ralston, 1987) implies the possibility that fishing may be the major selective force on harvested populations.

The time frame for such a response is a major fisheries management concern and depends on various factors including population genetics. Little is known specifically about reef fish genetics although it is reasonable to assume that genetic variability exists among individual reef fishes. Significant genetic variability has been shown among populations of queen conch (Strombus gigas), a highly dispersed reef species found around the greater Caribbean, even though gene flow is high (Mitton, et al., 1989). Rapidpopulation, genetic, and evolutionary responses are more likely during periods of high mortality when population size is greatly reduced (Eldredge and Gould, 1972; Wiens, 1977). Also, shorter generation times can speed up a selective response (Charlesworth, 1980). Human induced genetic changes have been shown in fishes despite the difficulties in detecting genetic changes. Fishing mortality on adults has been shown to drive Atlantic salmon (Salmo salar), normally a long-lived fish, into early spawning through differential phenotypic expression and genetic shifts in less that two decades (Montgomery, 1983; Rago and Goodyear, 1987). Ricker (1981) showed that due to selective harvesting the average size of chinook salmon (Oncorhynchus tshawytscha) declined by more than 50% within 60 years and the average age of maturity had declined by approximately 2 years. Pink salmon (Oncorhynchus gorbuscha) also decreased in size by 10 to 40% over a 25-year period.

Red Snapper Model

Red snapper (Lutjanus campechanus) life history and population dynamics were modeled as a representative and important reef fish. It has been traditionally the most valuable reef fish from the Gulf of Mexico and occurs from North Carolina to the Florida Keys and around the Gulf of Mexico to Yucatan, Mexico. Total annual commercial red snapper landings in the Gulf of Mexico have declined from 14 million lb. (6.4 million kg) in 1965 to a low of 4.1 million lb. (1.9 million kg) in 1986 (Waters, 1988). Recreational landings declined from over 5 million fish in 1979 to 1 million in 1986 and from around 12 million lb. (5.4 million kg) in 1980 to 1 million lb. (455,000 kg) in 1986 (Goodyear, 1988a). These declines in landings can be explained in part by reduced recruitment resulting from fishing mortality (Goodyear, 1988a; 1989). Goodyear (1988a) estimated that spawning stock biomass per recruit was between 1.5% and 1.8% of the unfished level with fishing mortality rates of 0.75 for fishes first recruited to the fishery and 0.34 for older fish.

Individual red snapper commonly live 9 to 11 years, and may live up to 20 years, reaching sizes of 18kg (39.7 lb.) and 90 cm (36 in) (Beaumariage and Bullock, 1976; GMFMC, 1981; Nelson and Manooch, 1982). Estimated annual natural mortality is low at 17% (Nelson and Manooch, 1982). Fecundity is difficult to estimate although older and larger fish produce the bulk of eggs and sperm. Individuals may reach sexual maturity after age two (Gulf of Mexico Fishery Management Council, 1981). Reported female lengths at first maturity varies from 25.5 cm FL in the northwestern Gulf of Mexico (Bradley and Bryan, 1975) to 33.4 cm FL off southwest Florida (Futch and Bruger, 1976). Grimes (1987) reported maximum fecundity of 9.32 million eggs (746/gm of body tissue) in a 60.5 cm FL (12.5 kg) fish and minimum fecundity of 44,000 eggs (4/gm body tissue) in a 42 cm FL (1.1 kg) fish. Using these numbers, one large red snapper female (approximately 8 to 10 years old) produces the same number of eggs as 212 small (approximately 3 to 4 year old) females (Fig. 6). Individuals may spawn more than once during a season and larger females may spawn more times and over a longer period than smaller females (Grimes, 1987).

Projected effects of fishing mortality on a cohort of 10,000 red snapper were estimated (Fig. 7a) based on low (Z = -0.38, F = 0.21, Carolinas) and high (Z = -0.78, F = 0.58,

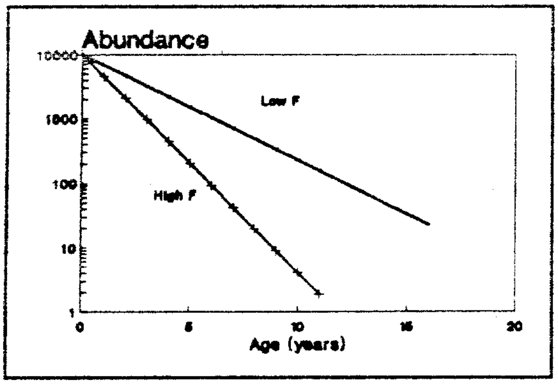


Figure 7a. Effects of high and low fishing mortality (F) on abundance starting with a cohort of 10,000 fish.

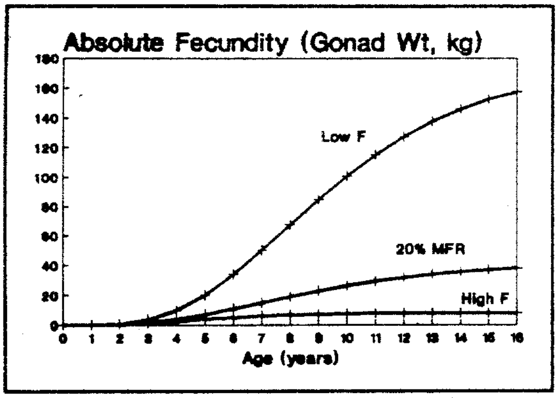


Figure 7b. Absolute fecundity under high and low fishing mortality (F) and with 20% of a stock protected with low fishing mortality and 80% under high fishing mortality (20% MFR).

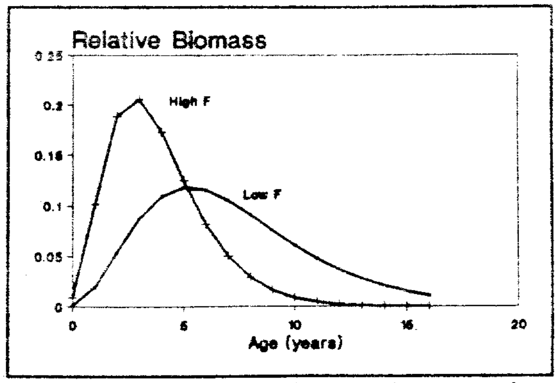


Figure 7c. Relative biomass by age class under high and low fishing mortality. Curves do not reflect total biomass.

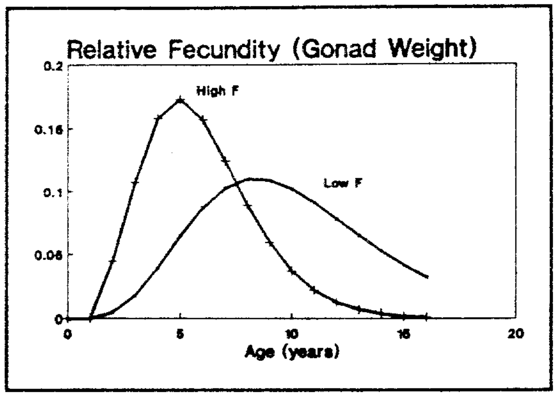


Figure 7d. Relative fecundity by age class under high and low fishing mortality. Total fecundity is shown in Fig. 7b.

Louisiana) fishing mortality rates (Nelson and Manooch, 1982) using the following conversion equations by Goodyear (1988a):

$$\ln(gw) = -16.1 + 5.87 * \ln(L)$$

$$L = 45.9(1-\exp(-0.115(age+0.50)))$$

$$\ln(W) = -7.79 + 3.07 * \ln(length)$$

where gw is gonad weight in grams, L is total length in inches, and W is weight in lbs.

Fishing mortality has major impacts on age class structure, survival, and fecundity. While approximately 300 individuals would survive to become nine years old under low fishing mortality, less than 10 would survive under high fishing mortality (Fig. 7a). Under high fishing pressure total fecundity is only 5% of that at low fishing pressure (Fig. 7b), however, protecting 20% of the stock at low fishing effort will increase total fecundity approximately five times over what would occur under heavy fishing pressure. The year class with the greatest biomass is composed of five year old fish under low fishing mortality while three year old fish have the most biomass under high fishing mortality (Fig. 7c). Eight year old fish have the greatest fecundity under low fishing pressure while the greatest fecundity is provided by five year old fish under high fishing pressure (Fig. 7d).

This model is conservative in that it underestimates the full impact of fishing mortality on fecundity: (1) assuming some senescence, no fecundity was provided for fishes over age 16; (2) only one reproduction event was assumed per year although older fish may reproduce more often; and (3) some fishing mortality occurs at low fishing effort. With no fishing mortality, total survival and fecundity should be higher.

The red snapper model demonstrates how fishing reduces average age and total fecundity per individual. Shorter average ages reduces generation time and accelerates the potential detrimental selective effects of fishing. An additional problem of shorter life cycles is that a population becomes more vulnerable to recruitment variability due to environmental uncertainty. According to evolutionary theory, age spans are selected for to ensure that one generation lives long enough to replace itself. By reducing average age from over 8 years to 5 years, the population becomes vulnerable to collapse in the event of several poor recruitment years. Thus, a population could collapse even though fishing mortality was at an acceptable level for "average" conditions.

DISCUSSION

Some reef fish management problems are inherent to the fishery while others are exogenous administrative or practical problems. Major problems identified in the reef fish fishery due to fishing include:

1. Potential recruitment overfishing because of insufficient spawning stock biomass;
2. Increased probability of recruitment failure due to environmental uncertainty and shorter generation times;
3. Loss of genetic diversity within species resulting in undesirable stock characteristics;
4. Growth overfishing for many species;
5. Declines in overall abundance and average fish size;
6. Loss of biotic (interspecific genetic) diversity;
7. Potential disruptive reef fish community instability and permanent alterations; and
8. Faster selection against desirable traits due to shorter generation times.

We concluded that some older fish are more valuable as egg producers and for protecting the quality of genetic composition than for the economic value of their flesh to the fishery. Continued fishing mortality at present levels is predicted to lead to greatly reduced numerical stocks, loss of genetic diversity, and an increased chance of fishery collapse due to natural ecological cycles. Fishery management policy must provide some protection for population age structure, species composition, and genetic variability.

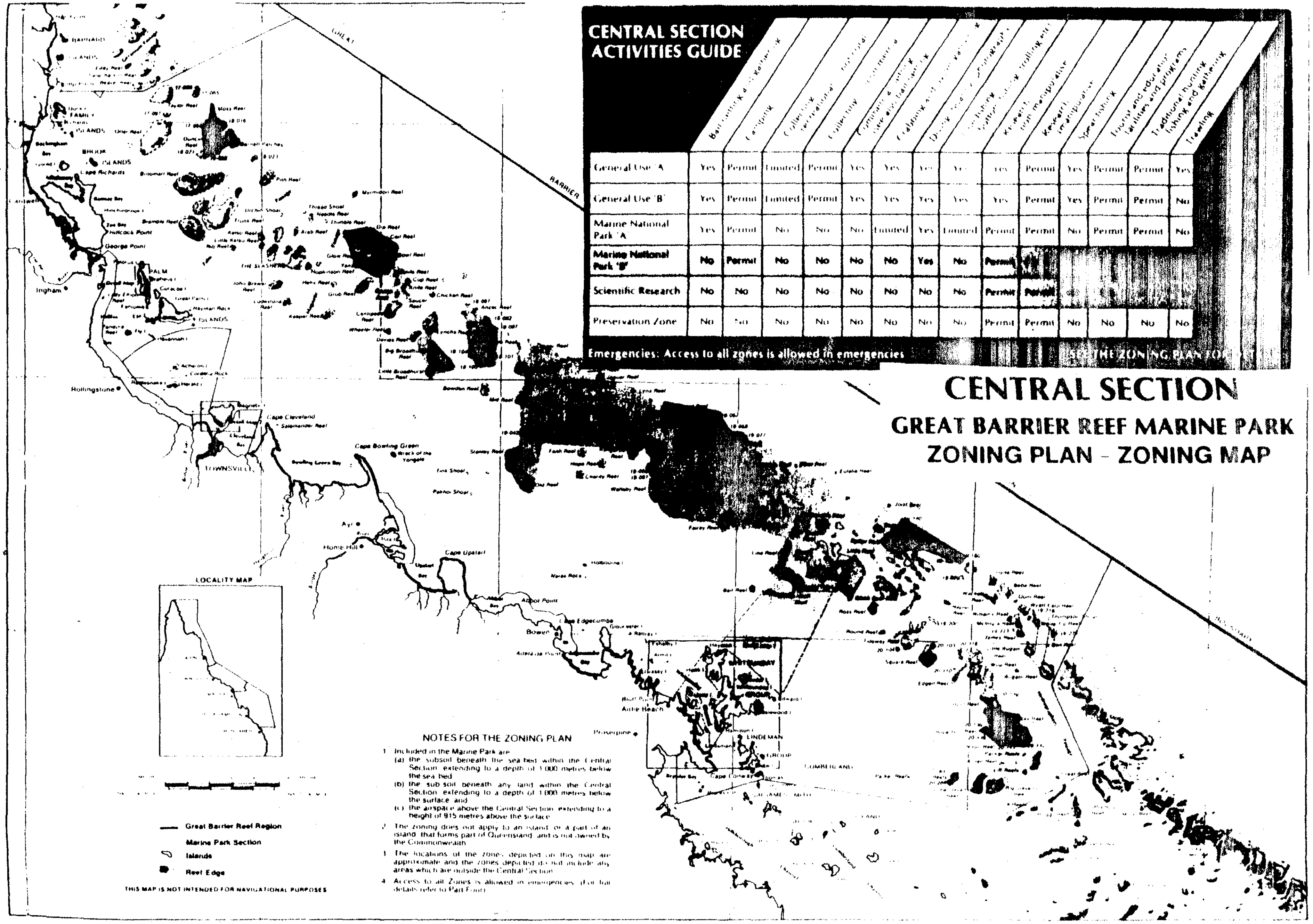
Marine Fishery Reserves

In this section the potential uses of marine fishery reserves are explored. This approach was investigated because of declining trends observed for many fishes in the SAFMC Snapper Grouper Plan and concerns about the effectiveness of current fishery management actions to control fishing mortality and solve the problems identified above for the most heavily exploited species. MFRs appear to offer the most potential for treating critical reef fish management problems that are not effectively treated by other traditional management strategies. Permanent reserves potentially protect intraspecific genetic diversity, community species diversity, population age structure, and protect recruitment supply from environmental variability. Below we examine general features of fishery reserves, make specific recommendations, and list their advantages and disadvantages.

General Considerations.

Marine fishery reserves (MFRs) are defined here as areas permanently closed to consumptive usage. Their purpose is to protect segments of reef fish populations from fishing mortality so that relatively undisturbed reef fish communities as well as population age structure can be maintained. Protecting large, older individuals is possible because many reef fish are relatively sedentary and remain in a limited area after settlement. Ultimately, these core areas will protect intraspecific and interspecific genetic diversity and ensure recruitment supply by

Figure 8. Zoning map of the Great Barrier Reef Marine Park Central Section.



CENTRAL SECTION ACTIVITIES GUIDE	Bait [illegible]	Camping	Collecting recreational [illegible]	Collecting [illegible]	Commercial [illegible]	Crabbing and [illegible]	[illegible]	[illegible]	Research, non manipulative	Research, manipulative	Spear fishing	Tourist and educational facilities and programs	Traditional hunting, fishing and gathering	Trawling
General Use 'A'	Yes	Permit	Limited	Permit	Yes	Yes	Yes	Yes	Yes	Permit	Yes	Permit	Permit	Yes
General Use 'B'	Yes	Permit	Limited	Permit	Yes	Yes	Yes	Yes	Yes	Permit	Yes	Permit	Permit	No
Marine National Park 'A'	Yes	Permit	No	No	No	Limited	Yes	Limited	Permit	Permit	No	Permit	Permit	No
Marine National Park 'B'	No	Permit	No	No	No	No	Yes	No	Permit	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Scientific Research	No	No	No	No	No	No	No	No	Permit	Permit	[illegible]	[illegible]	[illegible]	[illegible]
Preservation Zone	No	No	No	No	No	No	No	No	Permit	Permit	No	No	No	No

Emergencies: Access to all zones is allowed in emergencies

© Great Barrier Reef Marine Park Authority protecting spawning stock biomass. Normal pelagic dispersal of eggs and larvae are expected to resupply harvested areas.

History of Usage

The first marine protected area in modern times was established in the Dry Tortugas, Florida in the 1930's. Since then hundreds of protected marine areas (i.e. sanctuaries, parks, preserves) have been established internationallyfor a variety of purposes, although fishery benefits are often of secondary consideration (Clark, et al., 1989; Foster and Lemay, 1989; Tisdell and Broadus, 1989). Protection is typically incomplete or rarely enforced (Davidson and Gjerde, 1989). The most effective reserves have had local involvement and education, public input, and active management (White, 1986, 1988; Alcala, 1988; Kenchington, 1988; Foster and Lemay, 1989; Tisdell and Broadus, 1989).

Managers in the U.S. have been slow to utilize marine reserves for fishery purposes despite existing recommendations for establishing reserves for fisheries (Davis and Dodrill, 1980; Randall, 1982; Huntsman and Willis, in press). Although some areas have been protected from specific fishing activities such as trawling, trapping, and spearfishing, there are no areas protected from all hook and line fishing in the Caribbean, Gulf of Mexico, and Atlantic. Marine reserves for fishery purposes are actively used in Australia (Figure 8; Murdoch, 1989), South Africa (W. Fox, pers. comm.), and are currently being established in Bermuda (B. Luckhurst, pers. comm). The American Fisheries Society approved as policy the use of fishery reserves in a marine wilderness concept (Bohnsack, et al., 1989).

Potential Effectiveness

The potential success of MFRs in the U.S. southeastern Atlantic is predicted based on dramatic increases in fish abundance observed in areas protected from some fishing activities. Goeden (1982) showed a significant correlation ($r = 0.703$, $p < 0.0005$) between coral trout (Plectropomidae) density and distance from major human population centers. This correlation was attributed to reduced fishing intensity in more remote areas. Randall (1982) noted greater abundance and approachability of fishes in protected marine areas. In the Indo-Pacific, fishing bans have proved successful at maintaining fish abundance and diversity (Russ, 1985; White, 1986, 1988; Kenchington, 1988). After 10 years of no fishing at Sumilon Island Reserve, Philippines, protective management broke down and within 18 mo. the reserve showed significant decreases in both species richness and density of target and non-target species compared to control sites (Russ and Alcala, 1989). Total landings also declined around the reserve, suggesting that the reserve had provided fishes to the nearby harvested regions (Alcala, 1988).

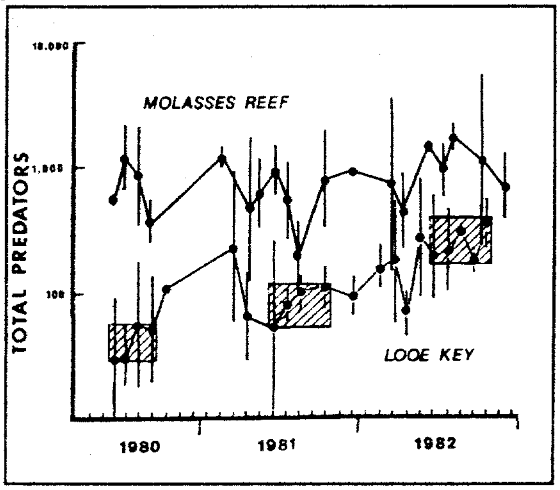


Figure 9. Increase in predatory fishes observed in 15 min while swimming at Looe Key Reef before and after partial fishing protection in 1980. Boxes show intensively sampled summer periods. Vertical bars show 95% CI.

In the southeastern U.S. partial fishery protection has been shown to be effective. Permanent lobster sanctuaries have shown dramatic improvements in population abundance and size (Davis, 1977; Davis and Dodrill, 1980). Bohnsack (1982) showed major differences in species presence, fish size, and abundance between Florida reefs protected versus those unprotected from spearfishing. After establishment of a spearfishing ban in 1980 in the Looe Key National Marine Sanctuary, Florida, total predator abundance increased exponentially during the first two years (Fig. 9). Molasses Reef served as a control reef, having been protected from spearfishing since 1960. At Looe Key Reef abundance of snapper increased by 93%, grunts by 439%, and hogfish by 1900% by 1983 (Clark et al., 1989). All 15 of the examined target species increased in abundance while 14 out of 15 increased in frequency. Many of the larger species that were frequent spearfishing targets had increased in abundance by an order of magnitude (Fig. 10).

Although promising, the full potential of U.S. southeastern Atlantic MFRs is unknown because there are no regional areas without any fishing from which assessments can be made. Areas without spearfishing have shown dramatic changes and yet spearfishing probably accounts for only a small proportion of the total fish removed. For example, in Biscayne National Park, Florida, spearfishermen comprise less than 10% of the boats (Tilmant, 1981) and 27% of fishermen (Jones et al., 1985), but only 10.5% of the total fish harvested by recreational fishing (n = 145,300 fish; Tilmant and Stone, 1984).

Design Factors

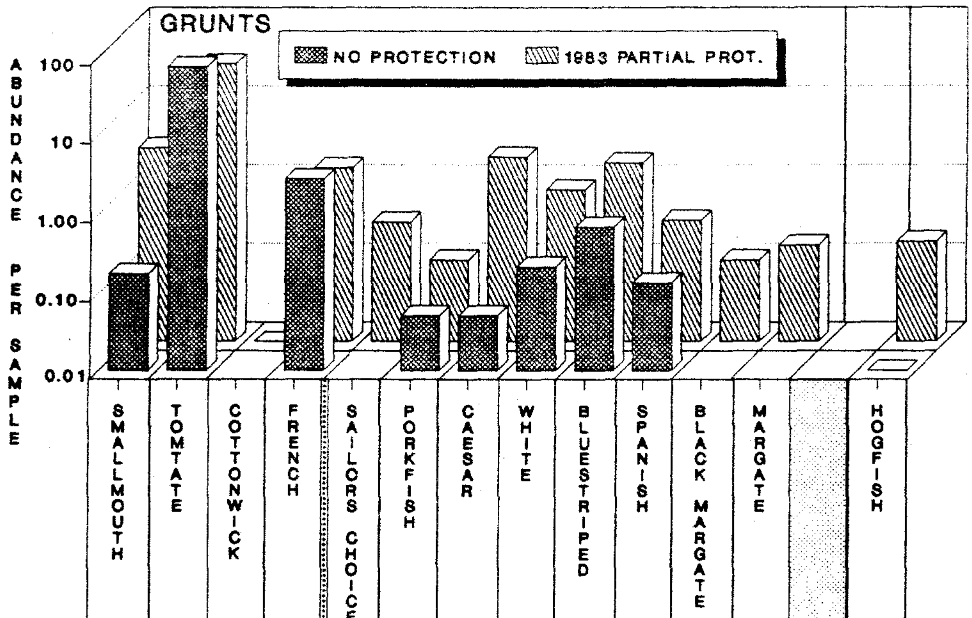
Many factors can influence MFR effectiveness. Important intrinsic considerations are the presence of target populations, the presence of necessary and sufficient habitat for all life history stages, reserve size (area), and the amount of edge (border). Extrinsic factors existing beyond MFR boundaries may influence reserve effectiveness, such as the presence of local fishing ports and urban centers, public awareness and acceptance, enforcement activity, and proximity of important adjunct habitat (White, 1986).

Little information exists on optimal size for marine fishery reserves despite considerable general literature on the design of wildlife reserves (Soulé and Simberloff, 1986) and the ability of refuges to protect populations (Taylor, 1984). Adequate reserve size depends on the biological characteristics of individual species, such as home range size, individual density, population age structure, and behavioral interactions. In general, larger MFRs are needed for species with larger home ranges and lower population densities. MFRs may not be effective for highly migratory species.

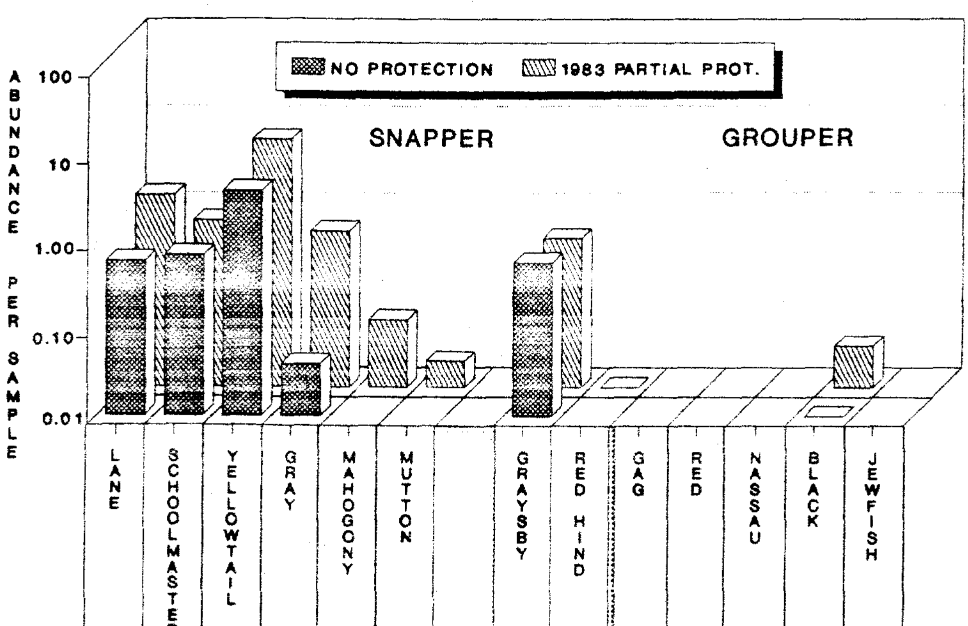
MFRs should include critical adult habitat and should be sufficiently large to support breeding populations with a stable age structure. Juvenile habitat should be included for species that utilize different habitats as juveniles, especially when juveniles are vulnerable to fishing mortality. Scientific knowledge is lacking on habitat distribution and requirements for most species. Each species has particular habitat needs. In different regions a variety of reef habitat types exist with different quality, quantity, and dispersion. Also, many reef species extensively use non-reef habitat for recruitment, growth, or foraging on an opportunistic or obligatory basis. Specific recommendations of minimum reserve size for reef fishes range from as low as 35 km^2 based on island biogeographic theory (Goeden, 1979) to "very large" tracts based on arguments that small areas are not self-perpetuating (Talbot and Anderson, 1978, cited in Kenchington (1988). Tisdell and Broadus (1989) discuss social and economic issues related to marine reserve design, size, and justification.

Fishery reserves boundaries should be simple and easily identifiable to prevent inadvertent fishing within a reserve. Highly contoured boundaries should be avoided to reduce "leakage," in which fishes wander out of a reserve where they become vulnerable to fishing. This leakage can be expected to be proportional to the length of boundary and inversely proportional to the enclosed area. When a refuge is small, the fraction of its population that could wander into a danger zone is increased (Taylor, 1984). The amount of leakage is expected to vary among sites, species, size categories, seasons, and weather conditions. High turbidity from storms has been shown to disorient some reef species (Ogden and Ehrlich, 1977) which may partially account for reports of unusual fishing success after storms. Leakage should have two beneficial effects on local fishing: migrating adults will occasionally wander into surrounding areas which will improve nearby fishing, and the occasional loss of a large adult will potentially help maintain trophy fisheries which tend to disappear under heavy fishing pressure.

Figure 10. Changes in fish populations under no protection (June 1979 - June 1981) and under partial fisheries protection two years after active enforcement (1983). Species are organized by family with smaller species on the left. Dotted vertical lines separate species that generally were too small to receive any harvesting changes due to a spearfishing ban. Grouper not observed in samples but observed at other times are shown without vertical bars. Data are from stationary visual samples (Bohnsack and Bannerot, 1986).



	SMALLMOUTH	TOMTATE	COTTONWICK	FRENCH	SAILORS CHOICE	PORKFISH	CAESAR	WHITE	BLUESTRIPED	SPANISH	BLACK MARGATE	MARGATE		HOGFISH
1983 PROT.	2.89	34.0	0.01	1.60	0.33	0.11	2.20	0.85	1.86	0.35	0.11	0.17		0.19
NO PROT.	0.17	72.7	--	2.70	--	0.05	0.05	0.21	0.67	0.13	--	--		0.01



	LANE	SCHOOLMASTER	YELLOWTAIL	GRAY	MAHOGONY	MUTTON		GRAYSBY	RED HIND	GAG	RED	NASSAU	BLACK	JEWFISH
1983 PROT.	1.59	0.81	6.92	0.62	0.06	0.02		0.51	0.01	--	--	--	0.03	--
NO PROT.	0.60	0.70	3.84	0.04	--	--		0.58	--	--	--	--	0.01	--

Specific Recommendations: The 20% Option.

The PDT recommends marine fishery reserves be established for 20% of the habitat while other traditional fishery management practices be applied to the other 80% of the habitat. Scattered marine fishery reserves are to be established throughout the U.S. southern Atlantic region with the goal of protecting a minimum of 20% of the reef fish spawning stock biomass (SSB). To achieve this goal, the PDT recommends including 20% of representative cross sections of the continental shelf as MFRs on the basis that removing 20% of the habitat from fishing protects 20% of the population and 20% of the spawning stock at equilibrium. Ideally, MFR sites will include representative shelf habitats in proportion to their occurrence and their importance to various species. The remaining 80% of the shelf will be managed by any of several traditional options selected by the council for optimizing yield. Non-consumptive resource use would be allowed in MFRs.

The target SSB was selected based on theoretical and empirical evidence that stocks are likely to collapse when they fall below 20% of the unexploited SSB level (Goodyear, 1989). In practice, SSB should be higher than the critical minimum 20% SSB level. The 20% MFR target assumes that the remaining 80% of the shelf will be effectively managed to optimize yield and allow the existence of additional spawning individuals. Without adequate management in fished areas, we recommend that MFRs be increased to include at least 30% of the shelf. In the red snapper model (Fig 7b), total fecundity under high fishing pressure was only 5% of that under low fishing pressure. However, protecting 20% of the habitat from fishing was predicted to increase total fecundity approximately five times over that which would occur under heavy fishing pressure.

Specific MFR sites selected for discussion purposes are presented in Appendix A. Sites were selected based on the best available scientific information although some uncertainty exists about the optimum number, location, and sizes of fishery reserves needed. The following seven criteria were used in addition to those given above:

A. Reserves must include representative reef and reef-associated habitats. Thus, reserves were proposed all along the southeastern U.S. coast. Boundaries begin at state waters and proceed to 150 fathoms to protect deep water species.

B. Reserves should be large enough to include sufficient and necessary habitat for supporting breeding populations with a stable age structure. A minimum shoreline distance of 20 miles (approximately 20' latitude) is suggested as a minimum dimension for biological effectiveness and easy enforcement. Most tagging studies show little reef fish movement (Appendix B). A 20 mi minimum longshore boundary was intended in part to minimize the effects of inadvertent fishing encroachment; even intrusions of up to a mile on either side still leaves 18 miles undisturbed by fishing.

C. Reserve boundaries should be minimized for biological purposes and selected for easy navigation and enforcement. For example, users may be better able to determine boundaries when based on lines of latitude and longitude or depth.

D. Where possible, MFRs should be "upstream" of settlement habitat to resupply fished areas.

E. When possible reserves should be established near areas with enforcement personnel (e.g. Coast Guard Bases, Marine Sanctuaries, State Parks).

F. Where possible, MFRs should be located near important inshore fishery habitats, such as major estuaries. Where appropriate, complimentary management should be encouraged by states to provide additional critical habitat.

G. Where possible, MFRs should be located away from major urban centers.

Anticipated Benefits.

Beneficial characteristics of marine fishery reserves include:

1. Protection of critical spawning stock biomass from fishery depletion. Fishery reserves can develop populations with different age and size classes, thus protecting the reproductive potential of the resident populations. A core spawning stock in MFRs potentially can supply fished areas with recruits because of the great dispersal capability of reef fishes. Each female can produce from hundreds of thousands to millions of eggs and larvae which are expected to disperse well beyond MFR boundaries by normal planktonic dispersal mechanisms (Doherty and Williams, 1988) (Fig 11). Passive drifting could carry some larvae hundreds of kilometers in a few weeks (Doherty and Williams, 1988), although in some circumstances mesoscale eddies may return some larvae to areas near their parents (Lobel and Robinson, 1986, 1988; Lobel, 1989).

2. Protection of intraspecific genetic diversity. Artificial selection pressure is removed from a portion of the population which should allow maintenance of genetic diversity. This genetic diversity could be maintained in the population by normal larval dispersal mechanisms. MFRs could be the major sources of total fecundity based on the red snapper model (Fig. 7b).

3. Maintenance of population age structure. The population age structure of various species within MFRs should reach a quasi-natural ambient state. This benefits total fecundity by maintaining spawning stock biomass, but also allows maintenance of social structure and behavioral patterns beneficial to the species.

4. Ensuring recruitment supply under environmental uncertainty. Fishing regulations, sensible under average conditions, may fail under extreme conditions. Maintaining areas with natural population age structure can protect the recruitment supply from recruitment failures. Recruitment problems can occur in a fishery because fewer age classes exist under exploitation (see Fig. 1;7a). In theory, natural population age structure is adaptive and is maintained by natural selection. Environmental uncertainty is one factor favoring older age classes. Fishing levels that allow spawning stock persistence under normal years can cause recruitment failure if several consecutive poor recruitment years occur as the result of annual environmental variation. Such environmental crunches, although rare, do occur and can be devastating to populations. Thus, recruitment failure is a potential problem due to environmental variation independent of fishing mortality.

5. Maintenance of areas with a natural equilibrium and ecosystem balance. This reduces the chances of unforeseen imbalances and community shifts. Excessive harvesting of keystone predators may throw ecosystems out of equilibrium and cause dramatic community changes (Goeden, 1982). Such changes have been documented in marine systems; the effects of sea otters on the abundance of sea urchins and kelp is one example (Estes and Palmisano, 1974; Palmisano and Estes, 1976; Simenstad, et al., 1978; Estes, et al., 1982). On a theoretical basis, such biological interactions are predicted to be more important in tropical reef ecosystems (Menge and Sutherland, 1976; 1987).

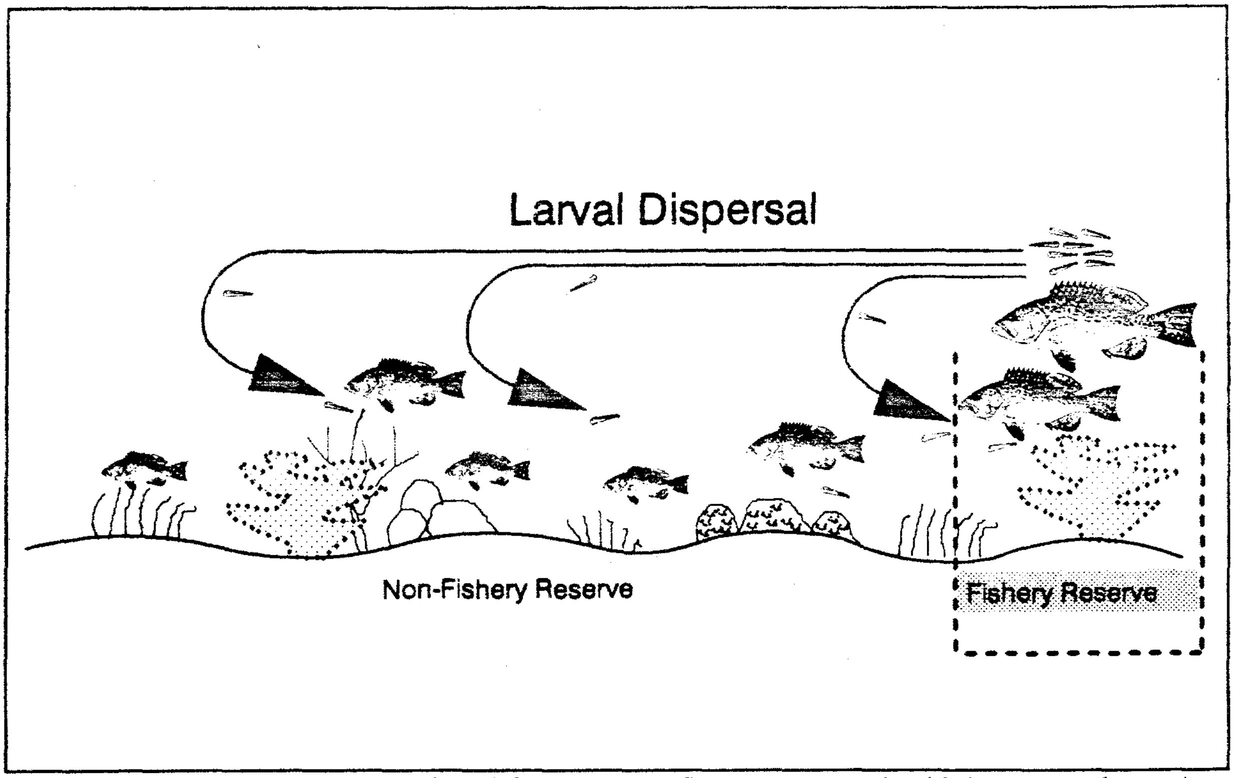


Figure 11. Many larvae generated by adults in marine fishery reserves should disperse and recruit to harvested areas.

6. Public understanding and acceptance. A fishing reserve is an inherently understandable concept that may be more readily accepted by the general public than other management strategies. Reserves seem to be a kind of common sense precaution against our ignorance as well as a mechanism for obtaining new knowledge. Terrestrial protected areas and wildlife reserves are common and widely accepted by the U.S. public. Australia and South Africa extensively utilize MFRs as important components in their fishery programs, while elsewhere protected marine areas are becoming more numerous worldwide as a major marine resource management tool (Kenchington, 1988; UNEP/IUCN 1988; Foster and Lemay, 1989). White (1986; 1988) notes that the most effective reserves have had legal support from national and local officials, the participation of local communities in reserve planning and implementation, and good local educational programs.

7. Insurance against management failure. MFRs will provide some insurance against management failure by protecting a portion of the population in the event management strategies fail in non-reserve areas. MFRs can provide a basis for rebuilding depleted stocks. This bet-hedging strategy is an important benefit considering the numerous stock collapses that have occurred in U.S. fisheries, the many management measures that are untested, collected data that are of uncertain accuracy, and fisheries that often change dynamically in ways that are difficult to anticipate.

8. Protection from serial overfishing. MFRs will provide refugia for stocks vulnerable to serial overfishing. Fishing mortality continues for some reef fish

species, despite severely reduced population sizes because of their high catchability and vulnerability to non-selective fishing gear.

9. Fairness and equitability. MFRs are fair and equitable in that they prevent use by all consumptive fishery users. No group is favored at the expense of others. Sites suggested for discussion purposes (Appendix A), however, were selected away from major urban areas which may reduce impacts on recreational fishermen.

10. Reduced data collection needs. Data collection needs are a problem with many reef fish management alternatives. However, complete information and understanding about complex ecosystem interactions is not essential for MFR management. This system assumes that populations will reach and maintain their own semi-natural equilibrium, making detailed data collection unnecessary.

11. Persistence of trophy fisheries. MFRs will allow large individuals to be maintained in the population, some of which will wander out of the reserve and be subject to fishing. This diffusion process may allow limited trophy fisheries to exist for some reef fish species.

12. Supplemental restocking. MFRs will act as a source for restocking harvested areas as some juveniles and adults move out of reserves (Russ and Alcala, 1989). This is expected to be a secondary effect and is not intended to act as the major source of fishes in harvested areas. Normal larval dispersal and recruitment from MFRs will be the primary sources of restocking. Marine reserves should work better at resupplying surrounding areas than do terrestrial reserves established for birds and mammals. Birds and mammals each produce relatively few offspring and rely heavily on parental care for learning and habitat choice. Female fishes produce huge numbers of offspring which are dispersed widely by currents, rarely settling in the same area as their parents (Doherty and Williams, 1988); parental care is non-existent.

13. Provision of fishery research areas. MFRs will provide potential research sites with a natural species equilibrium that will allow measurement of age, growth, and natural mortality for fisheries purposes. Currently, examining some of these problems is impossible because older individuals have been depleted and the natural balance of species has been severely disturbed.

14. Provision of minimally disturbed education and research sites. MFRs would maintain areas of minimally disturbed, natural reef community structure and ecological balance. These areas could be used for scientific, cultural, and educational uses that are not necessarily fishery related.

15. Protection of stocks from inadvertent fishing mortality. Problems of bycatch survival and hook-and-release mortality are avoided because there is no fishing and no opportunity for excess mortality.

16. Simplified enforcement. Geographically restricted reserve areas are easy to target for public education, awareness, and enforcement. Enforcement will be simplified because fishing in MFRs is prohibited; problems associated with measuring fish sizes and weights, species identification, and determining legality of fishing gear are eliminated. Violations can be easily detected by surface or aerial surveillance, often with public participation.

17. Reduction of incidental poaching. Incidental poaching occurs when normally law-abiding people are tempted to keep undersized, oversized, or individuals beyond quota or bag limits through normal fishing activities.

Because fishing is prohibited, the temptation for incidental poaching is nonexistent.

18. Enhanced interagency support. Many governmental and private agencies have educational and managerial responsibilities that are compatible with fishing reserves. These include: National Marine Sanctuaries, National Park Service, NASA, state agencies, Coast Guard, and private wildlife conservation groups. Increased public awareness, education, surveillance, and enforcement may be inexpensively obtained by cooperative agreements among organizations with facilities and personnel near MFRs.

19. U.S. leadership in reef fishery management. An international management strategy is appropriate and probably necessary for reef fishes because most reef species probably recruit from beyond national boundaries. Many developing countries look to the U.S.A. for fishery management leadership. MFRs will enable the U.S. to assume a leadership role in producing model strategies for cooperative international reef resource management in the Caribbean and U.S. southern Atlantic region.

20. Enhanced non-consumptive economic uses. In many instances secondary economic benefits such as tourism, diving, glass bottom boat tours, photography, educational group visits, etc. may compensate the local economy for any fishery loss and in some cases could exceed the direct value of the fishery (Van't Hof, 1985). This is especially likely in areas such as the Florida Keys which have close reef proximity and a well-developed tourist support infrastructure.

21. Increased management flexibility. Establishing MFRs can result in increased management flexibility by allowing greater fishing effort outside MFRs than would normally be acceptable and still avoid legally defined overfishing under the 602 guidelines for fishery management plans (Federal Register, 1989).

Anticipated obstacles.

Several problems and obstacles to establishing fishery reserves can be anticipated although some administrative mitigation is possible.

1. Institutional inertial resistance to change. MFRs are a new management approach in U.S. marine fisheries. As such, resistance can be expected, even if other management approaches have not worked.

2. Local opposition. Even with general public acceptance, opposition by special interests can be anticipated: many would prefer a MFR anywhere except where they traditionally fish. As partial compensation, fish moving out of MFRs may improve fishing.

3. Site uncertainty. Uncertainty exists concerning the optimum size, location, and number of reserves necessary to ensure persistence of reef fish populations.

4. Short-term landings decline. The inclusion of fishing habitat into fishing reserves will have temporary impacts on total harvest especially near MFRs. These losses should be compensated for by long-term increased recruitment supply and protection of the fishery as a whole.

5. Long-term loss of fishing area. Over the long-term, potential fishing habitat in MFRs will be unavailable for fishing. Obviously, this loss is intended to be compensated for by potential benefits of

MFRs for increasing fish abundance and recruitment in fished areas.

6. Increased incentive for deliberate poaching. The incentive for deliberate poaching may be increased within reserves because of greater abundance, density, and larger fish sizes than in surrounding areas. This problem can be countered by public education and awareness, enforcement, and use of significant disincentives (i.e. fines, penalties, revoking fishing privileges, etc.) to discourage deliberate poaching.

7. At-sea surveillance and enforcement. Direct enforcement is necessary to ensure the detection, apprehension, and discouragement of deliberate poaching and non-compliance. Reliance on dockside surveillance and enforcement is not likely to be effective. At-sea surveillance and enforcement will likely involve moderate costs (i.e. greater than simple dockside enforcement but less than what would be needed to enforce quotas and bag limits at a similar level of effectiveness). Adequate patrols are necessary to ensure a reasonable probability of detecting, identifying, and apprehending significant violators. The general public can be helpful in reporting violations, although "at sea" and perhaps some aerial surveillance may be necessary.

8. Loss of artificial reefs within MFRs. Artificial reefs within MFRs will be unavailable as fishing sites. New artificial reefs may need to be built to replace those lost by inclusion within fishery reserves.

9. Conflicts with other fisheries. Fishing for species not in the reef fish plan may cause conflicts and enforcement problems. Ideally, all fishery management plans should be coordinated with other fishing activitieswithin reserves, such as trolling for mackerel. If this is not possible and other non-reef fishery activities occur within MFRs, then no reef fish bycatch should be permitted.

10. Research needs. The proposed MFR plan is designed to work without additional research. However, some short-term (3 to 5 yr) research will be desirable to demonstrate and quantify the effectiveness of MFRs as a management strategy; this will facilitate public acceptance. Longer-term research would be necessary to precisely determine the ideal number, size, and specific locations necessary for reef fish management.

11. State Cooperation. Although the proposed MFR boundaries begin at the end of state waters, MFR effectiveness may be enhanced considerably if states include appropriate adjacent inshore habitat in a similar MFR program. Many reef species spend early life history stages inshore in estuaries or non-reef habitat before moving to reefs offshore. Extensive exploitation in these inshore areas could limit recruitment into adult habitats. In some cases MFR effectiveness may depend on protection of stocks from harvesting in state waters.

Alternative Management Strategies

Solutions to most fishery management problems require decreased total fishing mortality which involves either reduced total fishing effort; refuges in space, time, or population numbers; or a combination of these approaches.

Munro and Williams (1985) recognized ten administrative management options applicable to reef fisheries (Table 3). Below is a brief summary of the major advantages and difficulties with each management option for reef fishes.

Table 3. Administrative management options for reef resources. Modified from Munro and Williams (1985).

1. Size limits
2. Catch quotas
3. Seasonal closures
4. Pulse fishing (periodic closures)
5. Annual limited entry
6. Permanent limited entry
7. Habitat alteration (artificial reefs)
8. Supplementary stocking
9. Gear Restrictions
10. Permanent reserves.

1. Size limits. Size limits may involve minimum sizes, maximum sizes, or both (slot sizes). Minimum size limits are frequently used in marine fisheries management, being rationalized as ensuring that a sufficient fraction of the recruits were given an opportunity to breed and to maximize the catch biomass (Larkin, 1978). Setting effective size limits requires precise knowledge about the growth and mortality of each species. Size limit effectiveness generally depends on good compliance and low release mortality (Waters and Huntsman, 1986). Goodyear (1988b) showed that even a 20% release mortality of undersized fish released upon capture could have great impacts on yield that essentially negate the benefits of size limits. Nelson and Soulé (1987) noted that size limitations often encourage a reduction in the number of breeding year classes to a destabilizing one or two and produce powerful size-selective forces with as yet unknown consequences.

   In theory, upper size limits potentially could protect older individuals. However, the effectiveness of maximum size limits is questionable because of the higher economic value of larger individuals and the problems of incidental release mortality (Waters, and Huntsman 1986; Goodyear 1988b).

2. Catch quotas. Catch quotas usually involve bag limits for recreational fisheries and total weight limits for commercial fisheries. Bag limits require precise and accurate predictions of recreational fishing effort, catch, landings, and release mortality which are not currently possible. Once bag limits are reached, some fishermen continue to fish, keeping larger or more desirable fish and returning dead ones. Bag limits and commercial quotas require a comprehensive, accurate, and real time monitoring of reef fish landings which is currently not realistic or economically practical. Species are easily misclassified and enforcement is nearly impossible because of the complexity of the reef fish fishery (i.e. the number of ports, dealers, gear types, species, and difficulty of species identification). Both approaches produce unreported and unknown amounts of discards, bycatch (from the commercial fishery), and release mortality (from the recreational fishery). Even with quotas, fishing will tend to target the larger, more valuable individuals which does not solve the major recruitment and genetic selection problems.

3. Seasonal closures. Seasonal and temporary area closures can be beneficial in protecting stocks when they are particularly vulnerable to fishing effort such as during spawning periods. However, they are unlikely to be totally effective because of the long life of most reef fish. Fishing pressure in the open season can be sufficient to impact older fish. Also, injudicious temporal closures may produce selective pressures on sex ratio or on the timing of the breeding season with unknown consequences (Nelson and Soulé, 1987).

4. Pulse fishing. Pulse fishing primarily reduces growth overfishing. It increases yield by allowing more time for growth. However, pulse fishing probably is of minimal benefit to

population age structure, fecundity, or genetics if pulse intervals are less than the average population life expectancy. This is unlikely to be a viable solution because the optimum pulse interval varies greatly between species and would probably be unacceptably long considering the average life expectancy of many reef fishes exceeds 10 years (Manooch, 1987). Increased fishing activity attracted to a newly opened area may quickly deplete stocks (Russ and Alcala, 1989). Davis (1977) observed a 58% reduction in trap catch rate and only 42% of lair occupancy density for lobster immediately following 8 months of recreational harvest in a previously closed area in the Dry Tortugas. Alcala (1988) noted a 26% drop in total fish abundance within 18 months of relaxed reef protection at Sumilon Island, Philippines. Lutjanids and lethrinids declined 94%. Rotating closed areas may create confusion, change geographical impacts on the fishery, and present some administrative and logistical problems for enforcement.

5. & 6. Annual and permanent limited entry. Annual and permanent limited entry can reduce fishing mortality if fishing effort is controlled at a sufficient level. Limited entry is easier to apply to a commercial fishery than to a recreational fishery, but is still difficult to monitor and enforce. This approach does not protect larger size classes from selective fishing.

7. Habitat alteration (artificial reefs). Although popular, the effectiveness of building artificial reefs for increasing reef fish populations has not been adequately demonstrated (Munro and Williams, 1985; Bohnsack and Sutherland, 1985; Bohnsack, 1989b). In theory, the practical benefits of artificial reefs are limited to very specific conditions and are unlikely to significantly increase production in a heavily fished fishery (Bohnsack, 1989).

8. Supplementary stocking. The effectiveness of supplementary stocking by mariculture or hatcheries has not been adequately demonstrated (Munro and Williams, 1985) and suffers from many theoretical and practical problems (Ryman and Utter, 1987). Especially troublesome are the potential mixing of stocks, resulting in breeding depression and genetic selection by hatchery operations (Courtenay and Robins, 1989). Other problems include the potential for spreading hatchery diseases into the wild population and uncertain survival in the wild of hatchery-reared juveniles. Although hatcheries could focus on selective breeding of desirable characteristics, desirable characteristics from a human perspective may not be adaptive in a wild population.

9. Gear restrictions. Gear restrictions are used to reduce stock catchability by selective fishing. Gear restrictions are usually applied to protect smaller individuals in the hope that more will survive to maturity. Selective fishing is less practical for protecting larger individuals because of long life spans, their higher market value, and greater vulnerability to most fishing gears (i.e. traps, hook and line, bottom long lines). Turner et al. (1983), for example, observed a decline in size of tilefish over time, suggesting that either fishermen avoided smaller fish or that larger fish, when present, outcompeted smaller fish for hooks. Gear restrictions can increase fishing costs but do not necessarily reduce fishing mortality. Fisherfolk frequently circumvent gear restrictions by adopting other technologies.

10. Permanent reserves. Permanent reserves are areas with no fishing. They potentially protect genetic diversity, community balance, and population age structure. This option is ideally suited for reef fishes because most post-settlement reef fish are relatively sedentary. Some at-sea enforcement and surveillance would probably be

necessary. This option was treated in detail earlier.

Evaluation of Alternative Management Approaches

Most of the above options do not address certain critical fishery problems, have only limited benefits, or can be easily circumvented. Options two through eight, for example, do not protect larger sized individuals because of their higher market values. Seasonal closures can be circumvented by more concentrated fishing in open seasons and artificial reef construction and supplementary stocking are unlikely to sufficiently increase reef fish stocks.

Participants in the Reef Fish Plan Development Team evaluated possible management approaches in terms of their potential to meet various defined objectives. This group represents professional fishery scientists. Options were ranked (Table 4) using a scale of 1 to 10 (10 the best option). Size limits were broken into two option categories with minimum size limits only and with minimum and maximum size limits. Only five respondents had the opportunity to evaluate the "status quo" option because it was added late. A combined total score for each option was not calculated because different problems have different levels of importance and combining scores would be meaningless.

Survey results clearly show that MFRs were considered the best possible approach for protecting stocks and reducing overfishing problems. Although based on small sample size, the status quo option was considered the least desirable approach. Stocking was also considered a poor overall alternative. Other options fell somewhere in between these two extremes.

Conclusions

Reef species are prone to overfishing due to their inherent life history characteristics. Under natural conditions most populations are believed to have low adult mortality and to be limited by recruitment variability. Fishing removes larger individuals, and, if uncontrolled, reduces the stock spawning potential, increases the chances for recruitment failure by environmental perturbations, and can select for undesirable stock characteristics. Because fishing harvests wild populations, it has become a major, if not the major, selective force acting on the adults of important harvested reef species. Predicted short-term impacts include recruitment failure and stock collapse. Many reef fish populations have collapsed or show signs of stress. Over the long-term, inter- and intraspecific genetic diversity will likely be lost, detrimentally impacting the resource for future generations. Major economically important species could become permanently scarce or become diminutive in size. All segments of the reef fish fishery stand to lose if present trends continue.

Marine fishery reserves are a management option with excellent potential to benefit reef fish fisheries. A mixed management strategy is recommended with 20% of the shelf designated as MFR while the remaining 80% is managed by any of several traditional options for optimizing yield. Reserves provides some insurance in case of failure by the traditional approach.

Traditional fishery management attempts to protect stocks by providing a refuge in numbers. The MFR approach differs by seeking to protect stocks by providing a refuge in space. This approach recognizes biological variation (all individuals are not the same). MFRs seek to protect older and larger individuals which supply the bulk of eggs and genetic input under natural conditions. Some of these individuals are more important as sources of recruitment quantity and quality than for the market value of their flesh.

Traditional fishery management approaches, using size limits, bag limits, gear restrictions, or quotas are unlikely to solve reef fish fishery problems because of enforcement difficulties, data collection difficulties, release mortality, increased fishing effort and effectiveness, and difficulty in monitoring all the species in the reef fish complex. These traditional approaches do little to reduce selective fishing and protect the genetic characteristics of the resource.

Table 4. Plan developement team evaluation of potential management approaches for reef fishes.

FISHERY PROBLEM	MANAGEMENT APPROACHES 1 Permanent Fishery Reserves	2 Seasonal Closures	3 Pulse Fishing	4 Limited Entry	5 Artificial Reefs	6 Stocking	7 Selective Fishing Gear	8a Minimum Size Limits	8b Maximum Size Limits	9 Bag Limits	10 Quotas	11 Status Quo
Protect Within Species Genetic Diversity	9.9	5.3	4.3	4.8	3.6	1.9	4.6	4.3	5.5	4.2	4.9	3.0
Protect Community Genetic Diversity	9.9	4.9	4.3	4.8	3.3	2.3	4.2	4.3	5.1	4.3	5.1	2.8
Protect Population Age Structure	9.9	4.9	4.3	5.1	3.3	2.5	4.4	4.7	6.4	4.3	5.1	2.5
Protection of Recruitment Supply from Environmental Variability	8.8	5.5	5.0	4.6	4.4	4.6	3.9	4.5	5.7	3.9	4.4	3.8
Protect Spawning Stock Biomass	8.8	6.5	5.4	5.3	4.4	5.0	4.8	4.5	6.8	4.5	5.2	3.0
Protect Spawning Aggregations	8.9	7.7	6.3	3.8	3.3	3.8	4.5	3.5	5.5	3.9	3.7	1.5
Reduce Growth Overfishing	8.3	6.1	5.1	6.1	3.5	3.1	6.3	7.1	4.4	5.5	5.7	3.0
Reduce Serial Overfishing	9.3	5.7	9.1	5.9	3.5	3.9	5.6	5.2	4.1	5.4	5.7	3.0
Reduce Ecosystem Overfishing	9.3	5.4	4.9	6.0	4.1	3.9	5.1	5.0	4.2	5.1	5.5	2.5
Reduce Bycatch Mortality	9.5	5.3	5.8	5.7	3.9	4.3	5.2	4.3	3.4	4.9	5.5	3.8
Reduce Release Mortality	9.7	6.0	6.1	6.3	4.3	4.0	5.8	4.2	3.1	4.8	5.7	3.8
Insurance for Management Failure	9.6	5.7	4.5	5.4	4.1	4.9	5.5	5.0	4.8	4.1	4.8	2.3
Ease of Enforcement: Deliberate Poaching	6.5	6.5	5.5	7.2	7.0	5.7	4.7	5.5	5.3	4.9	5.5	4.8
Ease of Enforcement: Incidental Violations	6.6	6.2	5.4	7.1	7.2	5.3	5.2	5.4	5.2	4.9	5.3	5.0
Data Requirements (Short Term)	6.7	7.9	6.3	5.7	4.7	3.6	5.8	6.0	5.3	5.5	5.8	6.0
Data Requirements (Long Term)	7.1	7.9	6.6	5.6	5.3	4.3	5.9	6.2	5.4	5.7	5.7	6.3
Costs for Data Collection	7.1	7.5	6.5	5.6	7.0	5.9	5.6	5.9	5.1	5.1	4.7	6.3
Costs for Enforcement	6.0	7.3	7.1	5.8	5.9	5.3	6.2	6.0	5.7	5.4	5.1	5.3
Costs for Continued Management	6.9	7.1	6.5	6.0	6.5	5.5	5.0	6.1	6.0	5.9	5.3	4.3
Public Understanding	7.1	7.1	4.2	5.7	7.1	6.9	6.1	7.1	5.7	6.8	6.5	5.5
Public Acceptance	5.7	6.0	4.0	4.7	7.3	7.2	5.2	6.8	4.8	5.7	4.9	5.5
Ability to Maintain Trophy Fisheries	8.3	5.4	4.6	4.8	4.4	3.4	5.1	5.5	6.5	4.9	4.1	3.3
Ability to Maintain Natural Communities	9.9	4.8	4.0	4.7	3.4	2.7	4.5	4.1	4.7	3.8	4.0	3.5
Support for Non-Fishery Uses	9.5	5.2	4.3	4.9	5.8	3.2	4.4	4.2	4.7	4.2	3.9	4.0
Fairness and Equitability	8.5	6.2	4.0	4.4	5.5	6.5	4.6	7.7	7.0	6.3	4.9	7.3
Number of Respondents	10	10	10	10	10	10	10	10	10	10	10	4

Recommended Scales:
Rank = 1 to 10 with 10 best, 1 worst

MFRs appear to offer the most potential for addressing critical reef fish management problems that are not effectively treated by other traditional management strategies. Permanent reserves potentially protect intraspecific genetic diversity, community species diversity, population age structure, and the recruitment supply from environmental variability and fishery depletion of the spawning stock biomass. Fishery reserves will also maintain areas with a natural ecosystem balance and population age structure that can be used for non-consumptive purposes.

Anticipated obstacles to MFRs are resistance to a new management approach; local opposition by some special interests near proposed reserves; and some uncertainty concerning the optimal size, location, and number of reserves necessary to ensure persistence of reef fish populations and fisheries. Fishing interests located near MFRs would be most directly impacted by removal of fishing habitat; however, they are most likely to benefit by higher densities of fishes migrating out of MFRs. Many obstacles to establishing marine fishery reserves could be mitigated by appropriate administrative actions (Table 5). For example, building artificial reefs outside MFR boundaries would mitigate impacts on total available fishing habitat.

Conceptually, marine fishery reserves are a simple and easily understood idea: there is value in leaving a portion of the habitat in its natural state. This approach, while facilitating enforcement, deals with critical fishery problems not treated by other administrative management options. Although reserves may be used for non-consumptive uses, their primary purpose is to benefit marine fisheries by protecting the quantity and quality of recruits.

If using marine fishery reserves is chosen as a management option, establishing reserves would be facilitated by careful attention to public awareness and education about fishery problems and the limitations of various alternative management possibilities. Public involvement in locating and managing reserves is essential for MFR acceptance and effectiveness.

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Table 5. Summary of problems of Marine Fishery Reserves with possible mitigation or compensation.

1. Reduced fishing access.

   Possible mitigation:
   a. Fishing will be improved on a regional basis.
   b. Fish movements (leakage) will improve fishing around reserves.
   c. Artificial reefs deployed near MFRs may mitigate reduced accessibility.
   d. State waters (3 mi) are not affected by SAFMC reserves.
   e. Locate MFRs in remote areas.
   f. Non-consumptive uses may compensate fishing loss (e.g. diving, sightseeing, tourism).

2. Uncertainty exists on necessary reserve size, number, total area, and location.

3. Reserves will be less effective for highly migratory species.

4. Excessive leakage to surrounding areas may limit effectiveness.

5. Increased economic incentive for deliberate poaching.

6. At-sea enforcement and surveillance needed.
   Compensation: fines for violations may compensate enforcement costs.

7. Continued fishing activities for non-reef species hinder protection.
   Possible action:
   a. Implement no reef fish bycatch rule.
   b. Coordinate other management plans to prevent all fishing.

8. Artificial reefs and SMZs may need to be relocated or replaced.

9. Habitat protection may need to include state waters.

10. Need improved non-destructive, fishery-independent, assessment methods (video, acoustic, and visual) for monitoring stocks in MFRs.

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APPENDIX A

Possible U.S. Southern Atlantic Marine Fishery Reserves

The following eight sites (Figure A1) were selected for discussion purposes as potential marine fishery reserve sites. Criteria used to select sites are presented in the text.

1. Dry Tortugas.

Boundaries: South, EEZ or 150 fathom depth contour; Area: 360 n. mi.^{2} (to 150 ftm).
East, 82° 40';
West, 83° 00';
North, GMFMC boundary, Florida waters, and Fort Jefferson National Monument.

Reasons for selection: This area is upcurrent and a potential source area for recruits to the Gulf of Mexico and the Florida Reef Track. The Tortugas banks to the west are still available for fishing. National Park Service personnel located at Fort Jefferson National Monument are logistically well positioned to monitor fishing regulations in the reserve.

2. Lower Florida Keys.

Boundaries: North, Florida waters; Area: 360 n. mi.^{2} (to 150 ftm).
East, 81° 20';
West, 81° 40';
South, EEZ or 150 fathom depth contour.

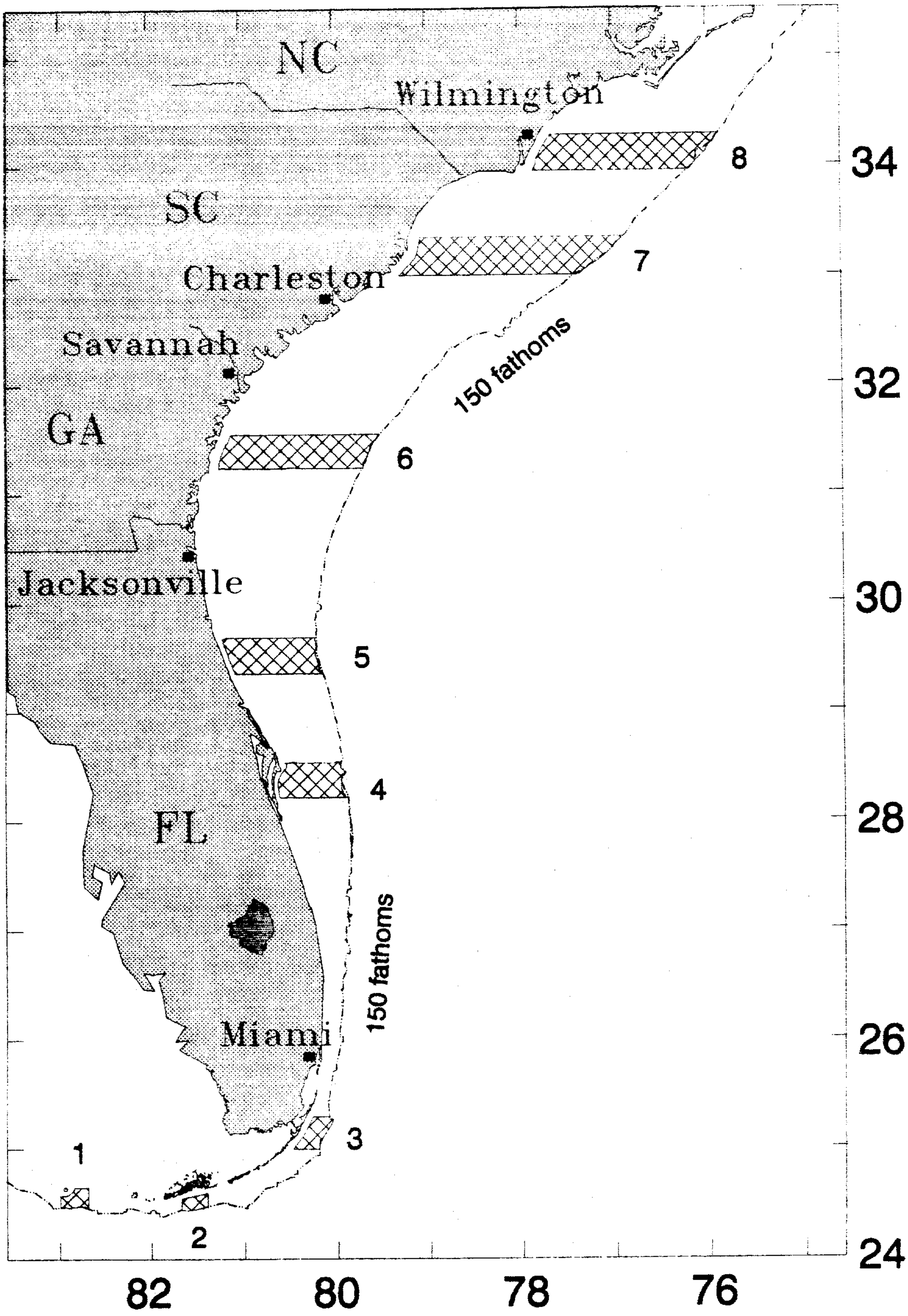
Reasons for selection: Considerable reef habitat exists in this area and the adjacent land is not as densely inhabited as areas to the west and east. The Pourtales terrace is located offshore and the Pourtales gyre may be an important recruitment mechanism for the Keys. The Looe Key National Marine Sanctuary is included in this site and their staff could possibly monitor fishing regulations in the reserve.

3. Upper Florida Keys.

Boundaries: West, Florida waters; Area: 280 n. mi.^{2} (to 150 ftm).
North, 25° 20';
South, 25° 00';
East, EEZ or 150 fathom depth contour.

Reasons for selection: Much of the area is included in Key Largo National Marine Sanctuary and adjacent to John Pennekamp State Park and Biscayne National Park. These areas have some restrictions presently. KLNM Sanctuary, Pennekamp State Park, and Biscayne National Park personnel are located nearby for enforcement and monitoring purposes. The Everglades and estuarine ecosystem and Florida Bay are adjacent. North Key Largo is not heavily populated compared to the Miami area and Upper Keys. Other reef areas are nearby and available for exploitation.

Figure A1. Possible marine fishery reserve sites along the southeastern U.S.



4. Cape Canaveral.

Boundaries:	West,	Florida waters;	Area: 759 n. mi.^{2} (to 150 ftm).
	North,	28° 30';	
	South,	28° 10';	
	East,	150 fathom depth contour.	

Reasons for selection: The site is adjacent to Merritt Island Estuarine Sanctuary, NASA presently patrols the area for missile launches, and the shelf is reasonably wide with representative reef habitat. A U.S. Coast Guard base is located nearby. The heavily populated areas to the south are avoided.

5. Flagler Beach.

Boundaries:	West,	Florida waters;	Area: 1080 n. mi.^{2} (to 150 ftm).
	North,	29° 40';	
	South,	29° 20';	
	East,	150 fathom depth contour.	

Reasons for selection: The site is away from highly developed areas (midway between Jacksonville and Daytona Beach), and the shelf includes representative reef habitat.

6. Georgia.

Boundaries:	West,	Georgia waters;	Area: 2001 n. mi.^{2} (to 150 ftm).
	North,	31° 35';	
	South,	31° 15';	
	East,	150 fathom depth contour.	

Reasons for selection: The site includes representative habitat and is remote from major urban areas. The site includes Gray's Reef National Marine Sanctuary whose personnel could potentially monitor regulations.

7. South Carolina.

Boundaries:	West,	South Carolina waters;	Area: 2508 n. mi.^{2} (to 150 ftm).
	North,	33° 20';	
	South,	33° 00';	
	East,	150 fathom depth contour.	

Reasons for selection: The site includes representative inshore, midshelf and offshore reef habitat.

8. North Carolina.

Boundaries:	West,	North Carolina waters;	Area: 2003 n. mi.^{2} (to 150 ftm).
	North,	34° 10';	
	South,	33° 50';	
	East,	150 fathom depth contour.	

Reasons for selection: The site includes representative inshore, midshelf, and offshore reef habitat. Sites north of Cape Lookout were considered too sensitive to environmental perturbation.

Appendix B

Reef fish movement based on tagging studies

Direct observations of daily reef fish movements have been made for only a few species. Starck and Davis (1966) reported that gray snapper (Lutjanus griseus) and French grunt (Haemulon flavolineatum) range as much as a mile (1.6 km) from their daytime resting places at Alligator Reef, Florida. Ogden and Ehrlich (1977) reported that French grunt migrate 100 to 300 m away from home reefs in the Virgin Islands.

Tagging studies have shown that most reef fishes are highly philopatric (i.e. they show high fidelity to particular reef sites) (e.g. Springer and McErlean, 1962). Bardach (1958) showed that the greatest distances traveled in Bermuda were 1.5 mi (2.4 km) for Nassau grouper (Epinephelus striatus) and 12 mi (19 km) for red hinds (Epinephelus guttatus). Randall (1961) concluded that most reef fishes in the Virgin Islands were nonmigratory although tag returns showed that some individuals moved as far as 0.5 to 0.8 mi (0.8 to 1.3 km) for schoolmaster snapper (Lutjanus apodus), 7 mi (11 km) for yellowtail snapper (Ocyurus chrysurus), 8 mi (13 km) for blue parrotfish (Scarus coeruleus), 1 mi (1.6 km) for rock hind (Epinephelus adscensionis), 10 mi (16 km) for Nassau grouper (Epinephelus striatus), and 4 mi (6 km) for yellowfin grouper (Mycteroperca venenosa). Moe (1966) and Beaumariage (1969) found no significant movement (3 to 4 mi or 5 to 6 km maximum) for black sea bass (Centropristus striatus) off the west coast of Florida. Moe (1966) found maximum movements of 11 mi (18 km) for white grunt (Haeumlon plumieri) although most fish showed no seasonal and only slight random movements from the tagging site.

Although most reef fishes show little movement, some individuals may disperse over long distances. For example, Ansley and Harris (1981) found over 98% of all recaptured black sea bass off Georgia were taken within 1 km (0.6 mi) of their release site, however, one fish traveled 259 km (160 mi) in 31 days after the initial release. Tag returns for red grouper (Epinephelus morio) showed little movement off Florida, however one individual was captured 40 n.mi. (74 km) west of its capture site five years later and one individual was captured 155 mi (249 km) from the release site 329 days after tagging (Beaumariage, 1969). Most returns for gag grouper (Mycteroperca microlepis) were near the point of release although movements for four individuals were documented for 7, 7, 15, and 55 n. mi. (13, 28, and 102 km) (Beaumariage, 1969). MARMAP tagging studies conducted by SCWMRD indicate some movements by large gag grouper from South Carolina to southern Florida during the spawning season (Mark R. Collins, per. comm.) Red snapper tag returns were also predominantly from the areas of release although individuals were recaptured with displacements of 25, 75, 90, 95, and 150 n.mi (46, 139, 167, 176, and 278 km) from the release point (Beaumariage, 1969). Most of these recaptures were east to southeast of the release point although one moved west. Gray snapper moved up to 30 n.mi. (56 km) although most moved less than 5 n.mi. (9 km) (Beaumariage, 1969). Beaumariage (1969) found one of 14 tagged spadefish (Chaetodipterus faber) moved 12 n.mi. (22 km) although two others showed no significant movement. He also reported movements of up to 50 mi for bluefish (Pomatomus saltatrix), 385 mi for palometa (Trachinotus goodei), and 75 mi for sheepshead (Archosargus probatocephalus).

Beaumariage (1969) found little movement for the following species although conclusions were based on few tag returns and few tagged individuals:

Species		Returns	Total Tagged
Warsaw grouper	Epinephelus nigritus	1	1
Mutton snapper	Lutjanus analis	1	4
Yellowtail snapper	Ocyurus chrusurus	3	36
White grunt	Haemulon plumieri	1	179
Gray triggerfish	Balistes capriscus	6	58
Great barracuda	Sphyraena barracuda	6	19

Tagging studies have shown a general pattern of movement from shallow areas to offshore areas with increasing size for gag and red grouper (Moe, 1966; Beaumaridge, 1969), sheepshead (Gallaway, 1980; Gallaway and Martin, 1980), and barracuda (de Sylva, 1963). Starck (1971) reports offshore movements of gray snapper in the Florida Keys. Gallaway (1980), Gallaway and Martin (1980), and Rosman (1963) however did not find offshore movement for red snapper off Texas. Larger individuals within a species have been shown to roam further than small individuals (Springer and McErlean, 1962; Topp, 1963; Beaumariage, 1969).

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